Fundamental Critical Care Support: Surgical

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Managing Editor: Patricia Micek, MBA

Printed in the United States of America
First Printing, October 2021

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International Standard Book Number: 978-1-620751-13-8

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1 Rapid Response System

2 Arterial Blood Gas Analysis and Treatment

3 Brain Death

4 Organ Donation

PREFACE

Through the years, the Fundamental Critical Care Support (FCCS) family of educational programs has been an essential resource for frontline critical care learners and educators, teaching basic concepts to assess and manage the patient until an intensivist arrives, or the patient can be safely transferred to a higher level of care. Now, the FCCS family of products has been expanded to include Fundamental Critical Care Support: Surgical.

Until now, no standardized course has covered the most common urgent surgical conditions that can lead to critical illness. FCCS: Surgical augments and expands on FCCS essentials. Its primary purpose is to provide an in-depth and broad understanding of the initial care of the seriously ill surgical patient by providing a deeper understanding of the pathophysiology of this population. The increasing complexity of surgical procedures on sicker patients leads to a knowledge gap between surgical and nonsurgical providers in the initial care, stabilization, and disposition of seriously ill surgical patients, making this course necessary. This tool can help frontline providers better assess and address the needs of critically ill surgical patients, facilitating better utilization of surgical specialties or stabilizing patients when immediate surgical or critical care expertise is not available.

The course follows the standardized format of FCCS products. The chapters in this first edition have been carefully written, reviewed, and organized to reflect the most current guidelines and practices and are based on current evidence where applicable. Chapters begin with learning objectives and case studies that provide real-life examples and focus on key clinical findings and patient presentation. Using the case study as a jumping-off point maximizes learning and the flow of information.

To develop this course, the participation of a distinguished volunteer group of national and international multidisciplinary critical care experts was invaluable. Our thanks to the authors, support staff, and leadership of the

Society for bringing this course to completion. And a heartfelt thanks to our audience members who commit to improving patient care.

We hope FCCS: Surgical will help establish a tradition of offering educational content to those faced with critically ill surgical patients, thus promoting the mission of SCCM: Right Care, Right Now.

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Chapter 1

RECOGNITION AND ASSESSMENT OF THE SERIOUSLY ILL PATIENT

✓ Objectives

- Recognize the early signs and symptoms of critical illness.
- Describe a framework for the initial assessment of the seriously ill patient.
- Explain the DIRECT methodology as a framework to approach the initial management of critically ill patients.

Case Study

A 58-year-old man with a history of hypertension presents to the emergency department with a 3-day history of fever, cough, and increasing shortness of breath. On arrival to the hospital, the patient has a temperature of 38.5°C (101.3°F), heart rate of 118 beats/min, respiratory rate of 26 breaths/min, a blood pressure of 100/72 mm Hg, and a pulse oximetry reading of 90% on room air.

– What findings are potential clues to a seriously ill patient?

– Which aspects of the physical examination would you concentrate on initially?

- Which laboratory and radiographic investigations would you order for this patient?

I. INTRODUCTION

Clinicians often think that patients with a critical illness present with sudden acute clinical deterioration. However, in retrospect these patients usually have shown early signs and symptoms that could have clued clinicians to the potential of serious illness. Early identification of patients at risk for life-threatening illness makes it easier to manage them and is associated with improved patient outcomes. Time-sensitive interventions and early stabilization usually require less aggressive treatments and prevent further deterioration. Many clinical problems, if recognized early, can be managed with simple measures such as supplemental oxygen, respiratory therapy interventions, intravenous fluids, dextrose administration, or effective analgesia. The early identification of patients in trouble allows clinicians to identify the main physiologic problem, determine its underlying cause, and begin specific treatments. The longer the interval between the onset of an acute illness and the appropriate intervention, the more likely it is that the patient's condition will deteriorate, even to cardiopulmonary arrest. Several studies have demonstrated that physiologic deterioration precedes many cardiopulmonary arrests by hours, suggesting that early intervention could prevent the need for resuscitation, admission to the ICU, and other sentinel events. Many hospitals are using rapid response systems to identify patients at risk and begin early treatment. (See **Appendix 1** for further information on the organization and implementation of a rapid response system.) The purpose of this chapter is to describe the general principles involved in recognizing and assessing seriously or critically ill patients.

II. RECOGNIZING THE PATIENT AT RISK

Recognizing that a patient is seriously or critically ill is usually not difficult when there are clear signs and symptoms present. However, in early stages, some signs may be subtle and clinicians may not fully appreciate the severity of the clinical picture. Young and otherwise healthy patients are usually much slower to exhibit the typical signs and symptoms of acute illness than elderly patients or those with comorbidities and/or impaired cardiopulmonary function. Thus, recognition of serious illness in young and healthy patients may be more challenging. Individuals who are immunosuppressed or debilitated may not demonstrate a vigorous and clinically obvious inflammatory response. Some conditions, such as cardiac arrhythmias, do not evolve with progressively worsening and easily detectable changes in physiology but rather present as an abrupt change of state. In most circumstances, a balance exists between the patient's physiologic reserve and the acute disease. Patients with limited reserve are more likely to be susceptible to severe illness and to experience greater degrees of organ-system impairment. The goal for the clinician is to recognize the potential for serious illness as early as possible. Early recognition can facilitate time-sensitive interventions and offer patients the best chance of a good outcome. Identifying patients at risk for deterioration requires assessment of the current physiologic changes caused by their acute disease process as well as their potential physiologic reserve based on their chronic health issues and comorbid factors.

!

Patients seldom deteriorate abruptly, even though clinicians may recognize the deterioration suddenly.

!

A. Assessing Severity

!

Tachycardia in response to physiologic abnormalities (ie, fever, low cardiac output) may be increased with pain and anxiety or suppressed *in patients who have conduction abnormalities or are receiving ß-blocker medications.*

"How sick is this patient?" is one of the most important questions clinicians must answer because it will dictate the urgency needed to stabilize, treat, and ultimately triage a patient to the appropriate level of care. Evaluation of severity of illness in any given clinical situation starts with proper measurement of vital signs and other specific physiologic variables (**Appendix 1**). Obtaining a heart rate, respiratory rate, a well-measured blood pressure, temperature, and pulse oximetry can be completed efficiently and will set the basis for an accurate patient assessment. Acute illness typically causes predictable physiologic changes associated with both disease-specific and general clinical signs. For example, a patient's physiologic response to a bacterial infection may result in fever, delirium, shaking chills, and tachypnea. The most important step is to recognize these signs and initiate physiologic monitoring to quantify the severity of disease and take appropriate action. Sick patients may present with confusion, irritability, impaired consciousness, or a sense of impending doom. They may appear short of breath and demonstrate signs of a sympathetic response, such as pallor, sweating, or cool extremities. Symptoms may be nonspecific, such as nausea and weakness, or they may identify the involvement of a particular organ system (for example, chest pain). Therefore, a high index of suspicion is required when measuring vital signs: heart rate, blood pressure, respiratory rate, oxygenation, temperature, and urine output. Clinical monitoring helps to quantify the severity of the disease process, tracks trends and rates of deterioration, and directs attention to those aspects of physiology that most urgently need treatment. Studies have identified several clinical findings that independently predict a higher risk of mortality. Some of these findings include low blood pressure, oliguria, prolonged capillary refill time, and skin mottling. A recent prospective cohort study found that the presence of a higher respiratory rate, higher systolic blood pressure, lower central temperature, altered consciousness, and decreased urine output were independently associated with mortality when documented on day 1 of an ICU stay. When these findings were all present, they offered similar or improved prognostic abilities compared with validated severity of disease scores. The goals at this stage of assessment are to recognize that a problem exists and to maintain physiologic stability while pursuing the cause and refining treatment with the implementation of disease-specific interventions.

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Even normal vital signs may be early indicators of impending deterioration if they differ from prior measurements.

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B. Immediate Therapeutic Interventions

Making an accurate diagnosis in the acutely ill patient often must take second place to treating life-threatening physiologic abnormalities. In the early phases of evaluation, the clinician must identify any physiologic derangement that requires immediate attention with supportive therapeutic measures. Correcting the problem may be as simple as providing oxygen or intravenous fluids.

There may not be sufficient time for a lengthy pursuit of a differential diagnosis initially if the patient is seriously ill and needs to be stabilized. However, an accurate diagnosis is essential for refining treatment options once physiologic stability is achieved. The general principles of taking an accurate history, performing a brief, directed clinical examination followed by a secondary survey, and organizing laboratory and radiographic investigations are fundamentally important. Good clinical skills and a disciplined approach are required to accomplish these tasks.

III. INITIAL ASSESSMENT OF THE CRITICALLY ILL PATIENT

A framework for assessing the acutely ill patient is provided in **Table 1-1** and discussed below. Further information on specific issues and treatments can be found in later chapters of this text.

A. History

> *A primary and secondary survey approach is recommended in the assessment of a seriously ill patient.*

The patient's history usually provides the most valuable information for diagnosis. Many seriously ill patients may have altered levels of consciousness or confusion and are incapable of providing a reliable history. Often the current history, past medical history, and medication list must be obtained from family members, caregivers, friends, neighbors, medical records, or other healthcare providers. The risk of critical illness is increased in patients with the following characteristics:

- Emergency admission (limited information)
- Advanced age (limited reserve)
- Severe coexisting chronic illness (limited reserve, limited options for management)
- Severe physiologic abnormalities (limited reserve, refractory to therapy)
- Need for, or recent history of, major surgery, especially an emergency procedure
- Severe hemorrhage or need for a massive blood transfusion
- Deterioration or lack of improvement

- Immunodeficiency
- Combination of these factors

Table 1-1 Framework for Assessing the Acutely Ill or Injured Patient

	PRIMARY SURVEY **Initial Contact — First Minutes** What is the main physiological problem?	**SECONDARY SURVEY** **Subsequent Reviews** What is the underlying cause?
History	**Main features of circumstances and environment** • Witnesses, healthcare personnel, relatives • Main symptoms: pain, dyspnea, altered mental status, weakness • Trauma or no trauma • Surgical or nonsurgical • Medications and/or toxins	**More detailed information** • Present complaint • Past history, chronic diseases, surgical procedures • Hospital course (if applicable) • Psychosocial and physical independence • Medications and allergies • Family history • Ethical or legal issues, code status • Systems review
Examination	**Look, listen, feel** • Airway • Breathing and oxygenation • Circulation • Level of consciousness	**Structured examination of organ systems** • Respiratory system • Cardiovascular system • Abdomen and genitourinary tract • Central nervous and musculoskeletal systems • Endocrine and hematologic systems
Chart Review: Documentation	**Essential physiology, vital signs** • Heart rate, rhythm • Blood pressure • Respiratory rate and pulse oximetry • Level of consciousness	**Case records and note keeping** • Examine medical records, if available • Formulate specific diagnosis or differential diagnosis • Document current events
Investigations	• Arterial blood gas analysis (can obtain venous blood gas if arterial access not possible) • Blood glucose	• Laboratory blood tests • Radiology • Electrocardiography • Microbiology
Treatment	**Proceeds in parallel** • Ensure adequate airway and oxygen • Provide intravenous access ± fluids • Assess response to immediate resuscitation • CALL FOR ASSISTANCE FROM AN EXPERIENCED COLLEAGUE	**Refine treatment, assess responses, review trends** • Provide support for specific organ systems as required • Choose most appropriate hospital site for care • Obtain specialist advice and assistance

A complete history includes the present complaint, treatment history, hospital course to the present (if applicable), past illnesses, past surgical procedures, current medications, and any medication allergies. A social history, including alcohol, tobacco, or illicit drug use, and a family history, including the degree of physical, emotional, and psychosocial independence, are essential and often overlooked. The history of the present complaint must include a brief review of systems that should be replicated in the examination that follows.

Critical illness is often associated with inadequate cardiac output, respiratory compromise, and a depressed level of consciousness. Specific symptoms will typically be associated with the underlying condition. Patients may report nonspecific symptoms such as malaise, fever, lethargy, anorexia, or thirst. Organ-specific symptoms may direct attention to the respiratory, cardiovascular, or gastrointestinal systems. Distinguishing acute from chronic disease is important at this point because chronic conditions may be difficult to reverse and may act as rate-limiting factors during the recovery phase of critical illness.

B. Examination

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Ongoing deterioration or development of new symptoms warrants repetition of the primary survey followed by a detailed secondary survey.

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Look, listen, and feel. The patient must be fully exposed for a complete examination. The initial examination must be brief, directed, and concentrated on the basic elements of airway, breathing, circulation, and level of consciousness. As the treatment proceeds, a more detailed secondary survey should be conducted to refine the preliminary diagnosis and assess the response to the initial treatment. A full examination must be performed at some point and will be guided by the history and other findings.

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Tachypnea is the single most important indicator of critical illness.

Paradoxical breathing is a sign of severe respiratory compromise.

Remember the ABCs of resuscitation: airway, breathing, and circulation. The airway and respiratory system should be assessed first, as summarized in **Table 1-2**. Observe the patient's mouth, chest, and abdomen. There may be obvious signs suggesting airway obstruction, such as vomitus, blood, or a foreign body. The patient's respiratory rate, pattern of breathing, and use of accessory respiratory muscles will help to confirm and assess the severity of respiratory distress or airway obstruction. The respiratory rate should be assessed visually by counting the number of breaths because respiratory rates displayed on cardiac monitors are subject to different degrees of artifact and thus can be inaccurate. *Tachypnea is the single most important indicator of critical illness*. Therefore, the respiratory rate must be accurately measured and documented. Although tachypnea may result from pain or anxiety, it may also indicate pulmonary disease, severe metabolic abnormalities, or infection. Look for cyanosis, paradoxical breathing, equality and depth of respiration, use of accessory muscles, and tracheal tug. An increase in the depth of respiration (Kussmaul breathing) may indicate severe metabolic acidosis. Periodic breathing with apnea or hypopnea (Cheyne-Stokes respiration) usually indicates severe brainstem injury or cardiac dysfunction. Ataxic breathing (Biot respiration) indicates severe neuronal damage, which is associated with a poor prognosis. Agitation and confusion may result from hypoxemia, whereas hypercapnia will usually depress the level of consciousness. Low oxygen saturation can be detected with pulse oximetry, but this assessment may be unreliable if the patient is hypovolemic, hypotensive, or hypothermic. End-tidal CO_2 monitoring is available on specific nasal cannulas as well as via ventilator tubing and is an appropriate adjunct monitoring device for patients at high risk for hypercapnic respiratory failure. Noisy breathing (eg, grunting, stridor, wheezing, gurgling) may indicate partial airway obstruction, whereas complete airway obstruction will result in silence.

Table 1-2 Assessment of Airway and Breathing

	Airway
Causes of Obstruction	Direct trauma, blood, vomitus, foreign body, central nervous system depression (with soft tissue or tongue blocking airway), infection, inflammation, laryngospasm
LOOK for	Cyanosis, altered respiratory pattern and rate, use of accessory respiratory muscles, tracheal tug, paradoxical breathing, altered level of consciousness, nasal flaring
LISTEN for	Noisy breathing (grunting, stridor, wheezing, gurgling); silence indicates complete obstruction
FEEL for	Decreased or absent airflow
	Breathing
Causes of Inadequate Breathing or Oxygenation	
Depressed respiratory drive	Central nervous system
Decreased respiratory effort	Muscle weakness, nerve/spinal cord damage, chest wall abnormalities, pain, substance abuse/overdose
Pulmonary disorders	Pneumothorax, hemothorax, aspiration, chronic obstructive pulmonary disease, asthma, pulmonary embolus, lung contusion, acute lung injury, acute respiratory distress syndrome, pulmonary edema, rib fracture, flail chest
LOOK for	Cyanosis, altered level of consciousness, tracheal tug, use of accessory respiratory muscles, altered respiratory pattern, altered respiratory rate, equality and depth of breaths, oxygen saturation
LISTEN for	Dyspnea, inability to talk, noisy breathing, dullness to percussion, auscultation of breath sounds
FEEL for	Symmetry and extent of chest movements, position of trachea, crepitus, abdominal distension

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A decrease in the blood pressure may be a late sign of cardiovascular disturbance signaling failure of the compensatory mechanisms.

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Inadequate circulation may result from primary abnormalities of the cardiovascular system or secondary abnormalities caused by metabolic disturbances, sepsis, hypoxia, or drugs (**Table 1-3**). Clinicians are primed to recognize low blood pressure as a worrisome sign. However, a normal blood pressure does not rule out severe underlying circulatory problems. Studies have shown that even transient drops in blood pressure are associated with worse outcomes. Central and peripheral pulses should be assessed for rate, regularity, volume, and symmetry. Capillary or nail-bed refill examination may aid in detecting hypovolemia if delayed. A combination of clinical findings (skin color, diminished distal pulses, decreased urine output, cool temperature of extremities, prolonged capillary refill) have been found to be useful in predicting low cardiac output states.

Evaluation of the patient's pulse can provide some clues to ongoing circulatory issues. Patients with hypovolemia or low cardiac output will have a weak and thready peripheral pulse. A bounding pulse suggests hyperdynamic circulation, and an irregular rhythm usually signifies atrial fibrillation or some other arrhythmia. A ventricular premature beat is often immediately followed by a compensatory pause, and the subsequent beat often has a larger pulse volume. Pulsus paradoxus is defined as a greater than 10 mm Hg decrease in the systolic blood pressure with deep inspiration; it can occur with profound hypovolemia, constrictive pericarditis, cardiac tamponade, asthma, and chronic obstructive pulmonary disease. Change in location and character of the left ventricular impulse (usually located in the fifth intercostal space in the left parasternal area) may suggest left ventricular hypertrophy, congestive heart failure, cardiac enlargement, severe mitral regurgitation, or severe aortic regurgitation. The turbulent flow of blood through a stenotic heart valve or a septal defect may produce a palpable thrill at the site of the left ventricular impulse.

Table 1-3 Assessment of Circulation

Causes of Circulatory Inadequacy	
Primary—directly involving the heart	Ischemia, arrhythmias, valvular disorders, cardiomyopathy, pericardial tamponade
Secondary—pathology originating elsewhere	Drugs, hypoxia, electrolyte disturbances, dehydration, sepsis, acute blood loss, anemia
LOOK for	Reduced peripheral perfusion (pallor) and delayed capillary refill, hemorrhage (obvious or concealed), altered level of consciousness, dyspnea, decreased urine output, jugular venous distension
LISTEN for	Additional or altered heart sounds, carotid bruits
FEEL for	Precordial cardiac pulsation, central and peripheral pulses (assessing rate, quality, regularity, symmetry), cool extremities

In addition to the ABCs, a quick external examination should look for pallor, cyanosis, diaphoresis, jaundice, erythema, or flushing. The skin may be moist or dry; appear thin, edematous, or bruised; or demonstrate a rash (ie, petechiae, hives). Fingernails may be clubbed or show splinter hemorrhages. The eyes might reveal abnormal pupils or jaundice. The conjunctiva may be pale, indicating an anemia. The patient may be alert, agitated, somnolent, asleep, or obtunded. These physical findings can help to guide decisions regarding differential diagnoses and the need for further testing.

Palpation of the abdomen is an essential part of the examination of the critically ill patient. Areas of abdominal tenderness and palpable masses must be identified. The size of the liver and spleen must be noted as well as any associated tenderness. It is important to assess the abdomen for rigidity, distension, fluid wave, guarding, or rebound tenderness indicating possible viscous perforation, infection, or peritonitis. Auscultation may reveal a vascular bruit concerning for an aneurysm or the absence of bowel sounds indicating a change in normal bowel patterns. A high suspicion for intrauterine or ectopic pregnancy must be considered in all women of childbearing age who present with lower quadrant pain. The flanks and back should be examined, if possible.

A neurologic evaluation in a potentially critically ill patient is focused on establishing changes in mentation/level of consciousness and quickly identifying focal deficits that could represent an underlying neurologic emergency. In young patients, slight changes in level of consciousness and mental status may represent serious underlying disease. In older patients with cognitive impairment at baseline, changes in mental status are commonly associated with serious illness and may be the first and only presenting sign. The Glasgow Coma Scale score should be recorded during the initial assessment of central nervous system function and limb movement. Pupillary size and reaction should be documented, and a more detailed assessment of central and peripheral sensory and motor functions should be undertaken when time permits.

C. Chart Review and Documentation

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Difficulty in obtaining a pulsatile waveform by pulse oximetry may be indicative of a vasoconstricted state.

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Critically ill patients have abnormal physiology that must be documented and tracked. Physiologic monitoring provides parameters that are useful only when they are accurate and interpreted by trained personnel. The values and trends of these data provide key information for the assessment of the patient's status and guidance for treatment. Data must be charted frequently and correctly to ensure good patient care. Particular attention must be paid to the accuracy and reliability of the data. For example, a true and reproducible arterial line pressure measurement depends on patient position, equipment calibration, and proper zeroing of the instruments. The source of the data also should be noted. Is the recorded temperature from an esophageal or Foley temperature probe? Was the blood pressure measured with a manual cuff or with a pressure transducer in an arterial line? Was the appropriate size of blood pressure cuff used? The medication record is an invaluable source of information about prescribed and administered drugs.

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An accurate measure of urine output, usually with an indwelling catheter, is essential in critically ill patients.

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Routine monitoring and charting should include heart rate, heart rhythm, respiratory rate, blood pressure, core temperature, fluid balance, and Glasgow Coma Scale score. The fluid balance should include loss from all tubes and drains as well as any fluids used to flush drains. The inspired oxygen concentration should be recorded for any patient receiving oxygen, and the oxygen saturation level should be charted if measured with pulse oximetry. Patients in the ICU setting may have central venous catheters or continuous cardiac output catheters in place. These catheters can measure central venous pressure, various cardiac pressures, stroke volume variations, cardiac output, and mixed venous saturation. These complex monitoring devices require specific operational expertise. Likewise, the data must be interpreted by someone with clinical experience and expertise in critical care. Finally, proper documentation of current continuous medication infusions along with the drip rate is especially important to provide an accurate picture of clinical condition.

D. Investigations

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The presence of a metabolic acidosis is one of the most important indicators of critical illness.

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Additional investigative tests should be based on information obtained from the patient's history and physical examination as well as on previous test results. Standard biochemistry, hematology, microbiology, and radiology tests should be performed as indicated. In the evaluation of electrolyte results, decreasing total serum carbon dioxide and/or an increased anion gap are evidence of metabolic acidosis. An arterial blood gas analysis is one of the most useful tests in an acutely ill patient, providing information about blood pH, arterial oxygen tension, and arterial carbon dioxide tension. Additional tests, such as lactate, blood glucose, serum electrolytes, and renal function, can often be obtained from the same blood sample. Increased levels of lactic acidosis have been associated with increased mortality in various critical conditions. Elevated lactic acid can be an ominous sign and should be closely monitored.

IV. TRANSLATING INFORMATION INTO EFFECTIVE ACTION

This chapter discussed a simple framework based on a primary and secondary survey as a basis for systematically approaching critically ill patients (**Table 1-1**). The primary goals of this framework are to first ensure physiologic stability and then proceed to treatment of the underlying cause. The basic principles are summarized as the ABCs of resuscitating the severely ill patient: airway— ensuring a patent airway; breathing—providing supplemental oxygen and adequate ventilation; and circulation—restoring circulating volume. These early interventions should proceed regardless of the situation, whereas the context of the clinical presentation (ie, trauma, postsurgical situation, presence of chronic illness, advanced age) directs attention to the differential diagnosis and potential treatments. The clinical history, physical examination, and laboratory tests should aid in clarifying the diagnosis and determining the patient's degree of physiologic reserve. Because the typical features of critical illness may be more effectively disguised in young and previously healthy patients than in elderly or chronically ill patients, an acute deterioration may seem to occur more abruptly in younger patients. Thus, it is particularly important to assess trends in vital signs and physiologic parameters as the patient undergoes treatment. These trends can help determine a patient's response and clarify the diagnosis.

More experienced help must be obtained if a patient's condition is deteriorating and there is uncertainty about the diagnosis or treatment. Transfer to the most appropriate site for care is influenced by local resources, but transfer to a high-dependency unit or ICU must be considered. Transfer to a tertiary care facility within the region may be necessary if resources at the current facility are not capable of caring for the patient.

Key Points

Recognition and Assessment of the Seriously Ill Patient

- Early identification of a patient at risk for critical illness is essential to improving patient outcomes.
- The clinical manifestations of impending critical illness are often nonspecific. Tachypnea and metabolic acidosis are two of the most important predictors of risk; they signal the need for more detailed monitoring and investigation.
- Resuscitation and physiologic stabilization often precede a definitive diagnosis and treatment of the underlying cause.
- A detailed history is essential for making an accurate diagnosis, determining a patient's physiologic reserve, and establishing a patient's treatment preferences.
- Frequent clinical and laboratory monitoring of a patient's response to treatment is essential.

Suggested Readings

1. Cretikkos MA, Bellomo R, Hillman K, et al. Respiratory rate: the neglected vital sign. *Med J Aust*. 2008;188:657-659.

2. Elder A, Japp A, Verghese A. How valuable is physical examination of the cardiovascular system? *BMJ*. 2016;354:i3309.
3. Hiemstra B, Eck RJ, Keus F, et al. Clinical examination for diagnosing circulatory shock. *Curr Opin Crit Care*. 2017;23(4):293-301.
4. Hiemstra B, Eck RJ, Wiersema R, et al. Clinical examination for the prediction of mortality in the critically ill: The Simple Intensive Care Studies-I. *Crit Care Med*. 2019;47(10):1301-1309.
5. National Institute for Health and Care Excellence (NICE) Guidelines. Acutely ill adults in hospital: recognising and responding to deterioration. Published July 2007. https://www.nice.org.uk/guidance/cg50. Accessed February 20, 2020.

Chapter 2

APPROACH TO THE SURGICAL PATIENT, PART 1: OVERVIEW OF THE CARE FOR THE CRITICALLY ILL PATIENT

✓ Objectives

- Describe the physiologic disorders that occur with surgery.
- Identify common complications that occur in critically ill surgical patients and their treatment.
- List the effects of anesthesia in the perioperative period.
- List and distinguish the different types of adverse drug interactions caused by anesthetics in the postoperative period.
- Describe the components in a successful handoff of a critically ill surgical patient to the ICU team.

Case Study

A 67-year-old man with a history of chronic obstructive pulmonary disease (COPD) and coronary artery disease presents with abdominal pain and distension accompanied by fevers, tachycardia, and hypotension, which is responsive to a fluid challenge. A workup reveals evidence of perforated sigmoid diverticulitis with free air and fluid throughout the pelvis. On examination, he has generalized peritonitis, and he is taken to the operating room and undergoes a sigmoid colectomy with creation of an end colostomy. At the time of the surgery, he has a large amount of feculent fluid throughout his pelvis with a significant inflammatory response. Intraoperatively he had significant bleeding requiring a blood transfusion and developed progressive hypotension requiring the initiation of a norepinephrine drip to maintain adequate blood pressure. His abdomen is irrigated, a colostomy created, and his fascia is closed primarily. He remains intubated and is admitted to the ICU postoperatively for further resuscitation and management. Several hours later, his abdomen is becoming progressively distended, his hemodynamics are worsening, and he is developing hypoxia with high peak airway pressures.

- What are the immediate interventions needed?
- What is the probable differential diagnosis?
- Is there any role for repeat surgical consultation or intervention?

I. INTRODUCTION

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> *Effective management of the postoperative patient involves attention both to basic critical care principles as well as specific issues related to anesthesia and the surgical procedure performed.*
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Critical care management involves well-defined principles that cross multiple medical specialties. However, there are numerous challenges in patient care that can affect the presentation and outcomes of patients who have undergone surgical procedures. Outside the specialties of surgery and anesthesia, there may not be a complete understanding of these situations and the immediate management considerations. Although the medical management of these patients is often very similar to the nonsurgical patient, lack of knowledge of some of the changes related to anesthesia and surgical care could significantly worsen the outcomes in this patient population. The goal of this text is to introduce the nonsurgical provider to the specific anesthesia and surgical changes that can influence the critical care management of this population. This chapter will concentrate on the changes in the physiology of the surgical patient, specific considerations regarding anesthesia care, considerations for care of the unstable patient in the postoperative period, as well as adequate transfer and handoff of information from the operating room to the critical care unit.

II. PHYSIOLOGIC CONSIDERATIONS IN THE SURGICAL PATIENT

The way the body responds to major systemic injuries depends on multiple factors. The physiologic reserve of a patient's organ systems, the nature of the injury, the time when the insult happens, the virulence of the damage, and the timeliness in recognition and resuscitation affect the body's response.

In the surgical patient, the primary cellular injury during the perioperative period is caused by direct surgical trauma, heating, vaporization, traction, or indirect damage from changes in global or local perfusion, which impairs oxygen and nutrient delivery. Some surgical patients can present as catastrophes in which the physiologic insult makes massive demands on the body's ability to respond, sustain life, and restore homeostasis. A secondary injury may be caused by the effect of locally released inflammatory mediators or hormones as a result of the stress related to the surgical procedure. The initial assessment also needs to consider many special populations, including pediatric, obstetric, geriatric, and obese patients.

A. Stress Response

In general, the stress response to surgery is proportional to the type of injury and the duration of the insult. The injury results in localized tissue trauma, which leads to release of cytokines and inflammatory mediators. These events drive a complex bundle of metabolic, hormonal, and immunologic responses in the body.

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Surgical procedures activate a stress response similar to other types of severe disease or injury.

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The goal is always to recognize problems early before the patient's physiology becomes significantly deranged. When successful, this usually allows for minimal intervention and will positively impact patient recovery. Performing regular assessments and promptly correcting abnormal physiology averts deterioration and prevents compensatory mechanisms from becoming overwhelmed.

Indirect cellular injury during surgery is caused by changes in the blood supply or oxygen and nutrient delivery. Early diagnosis requires continuous monitoring and repeated evaluation of organ function to detect early signs of organ dysfunction.

B. Volume Status

A fall in intravascular volume is often a crucial factor in the initiation of the systemic response. Perioperative hypovolemia has multiple potential causes, including:

- Blood loss as a result of trauma or surgery
- Plasma loss as a result of loss of integumentary system barrier function because of burns
- Abnormally high insensible losses from fevers, excess sweating, surgical exposure of abdominal contents, or hyperventilation
- Interstitial sequestration caused by epithelial dysfunction from injury or toxins
- Inflammatory exudate into the peritoneal cavity from multiple causes, including acute pancreatitis or generalized peritonitis secondary to intra-abdominal infection
- Sepsis syndrome with both relative and absolute hypovolemia as a result of peripheral vasodilatation and third-space losses from increased capillary permeability

Falling intravascular volume has several wide-ranging effects on normal physiology. Hypovolemia stimulates sympathetic activity by removing baroreceptor inhibition in an attempt to maintain blood pressure by increasing cardiac output and peripheral resistance. This explains the mild tachycardia commonly seen in postoperative patients. This compensatory mechanism is most effective in young fit individuals, and when it fails, decompensation is often sudden and rapid. This catecholamine response also has profound metabolic effects, increasing the turnover of carbohydrates, proteins, and lipids, resulting in a state of catabolism. Failing renal perfusion activates the renin-angiotensin-aldosterone system, increasing renal reabsorption of sodium and water. A centrally mediated increase in antidiuretic hormone (ADH) secretion promotes further conservation of intravascular volume.

C. Cardiac Output

Many factors can influence cardiac output and peripheral perfusion in the perioperative period. Circulatory efficiency may be impaired by hypovolemia, and myocardial contractility may be depressed by anesthetic agents and other drugs. Anesthetic drugs can cause peripheral dilatation, and positive-pressure ventilation diminishes venous return. Trendelenburg positioning and induced pneumoperitoneum for laparoscopic surgery can further stress cardiovascular physiology. Significant events such as sepsis, pulmonary embolism, or myocardial infarction may precipitate cardiovascular collapse. Uncontrolled pain in the peri- or postoperative period can lead to increased catecholamine and adrenocorticotrophic hormone secretion with similar effects.

D. Hypothermia

Hypothermia imposes enormous metabolic demands on the patient. Pediatric and geriatric patients are especially at risk. The causes are multifactorial, including excess heat loss during a prolonged surgical procedure or through skin with burn damage, as well as direct cooling caused by massive resuscitation. As the body core temperature falls, physiologic functions like perfusion and blood clotting are impaired. These changes place the patient at risk. In the adult patient, significant hypothermia can lead to multiple complications, including:

- Inhibition of tissue oxygen delivery
- Predisposition to dysrhythmias
- Coagulopathies (with difficulty in maintaining homeostasis and increased risk of bleeding-related complications)
- Electrolyte abnormalities
- Oliguria
- Shivering which increases oxygen requirements and potentially predisposes patients to cardiac ischemia and delay in wound healing

E. Coagulopathy

Response to injury is associated with blood coagulation changes. The general metabolic responses to injury activate thrombotic mechanisms and initially depress intrinsic intravascular thrombolysis. Thus, the postoperative patient is in a prothrombotic state and may sustain intravenous thrombosis and consequent thromboembolism. If substantial hemorrhage occurs, clotting factors eventually become exhausted, causing failure of clotting. Both processes can activate this inflammatory response and may initiate widespread intravascular thrombosis, depleting clotting factors and precipitating disseminated intravascular coagulation with failure of normal clotting.

F. Malnutrition

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Changes in intravascular volume status, cardiac output, coagulopathy, as well as malnutrition are common findings in the postoperative patient.

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Response to injury and surgical procedures are also associated with starvation and stress-induced catabolism. Patients with major surgical conditions are often malnourished before the surgery. Also, most patients are allowed nothing by mouth for 6–12 hours preoperatively, and many do not start eating for an extended period postoperatively.

G. Metabolic Responses to Pathophysiologic Stress

Glucose production is increased by catecholamine-induced gluconeogenesis. In addition, secretion of adrenocorticotropic hormone (ACTH) is enhanced. Multiple hormones contribute to the general catabolic response, including glucocorticoids (cortisol), glucagon, and growth hormone. Insulin acts as an antagonist of most of these substances and is secreted in increased amounts from the second and third day after injury.

In severe trauma or extensive surgeries, in particular, if they are complicated by sepsis, critical factors in the systemic response are increased because of sympathetic activity together with increased circulating catecholamines and insulin. Cytokine responses signal other cells to prepare for action to compensate for starvation, provide additional energy and building blocks for tissue repair, and conserve sodium and water.

In general, the activation of these multiple pathways is associated with a wide range of physiologic effects, including:

- Increased secretion of growth hormone and thyroid hormones, both of which inhibit the effects of insulin and promote catabolism
- Enhanced hepatic glycogenolysis and gluconeogenesis
- Lipolysis in response to catecholamines and glucagon, which releases fatty acids from adipose tissue; these provide the primary energy source for peripheral tissues
- Increased pituitary ACTH release induces a massive rise in circulating glucocorticoids; cortisol levels can increase tenfold immediately after surgery, remaining elevated for days or weeks
- Glucocorticoids also enhance gluconeogenesis and promote catabolism of muscle protein and liberation of amino acids
- Reduced insulin secretion and inhibition of its tissue effects which block cellular use of glucose
- Stimulation of glucagon secretion further enhances glycogenolysis and gluconeogenesis

In normal healthy adults, nitrogen balance is consistently maintained. Protein turnover results in daily excretion of 12–20 g of urinary nitrogen, which is replaced by dietary intake. In the hypermetabolic state, such as in the postoperative or trauma patient, nitrogen losses can increase substantially. Most importantly, the increased metabolic environment prevents proper use of enteric or parenteral nutrition. This process results in significant destruction of skeletal muscle. This state of negative nitrogen balance contrasts markedly with simple starvation in which body protein is preserved.

The effects of significant body insults on lipid metabolism are similar to simple starvation in that most of the energy requirements are met from fat stores. Surgical catabolism reverses only as the patient recovers from the illness, and therefore, early parenteral nutrition has little effect, although administration of carbohydrates may spare some protein loss. When the patient has been severely ill, carbohydrate metabolism is minimal, and most energy comes from the catabolism of protein and fat.

Multiple factors influence local perfusion to organs. Retraction of tissue, clamping or coagulation of blood vessels, and mobilization of the bowel can alter regional perfusion and compromise the delivery of oxygen and nutrients, leading to cellular dysfunction. Local perfusion may also be affected during pneumoperitoneum because of direct pressure effects and changes in oxygen delivery and impact on vital organs. Even after surgery, there is evidence that microcirculatory blood flow around surgical sites, such as anastomosis, can be impaired for a significant period postoperatively even in the face of normal global oxygen delivery.

Fluid, electrolyte, and acid-base derangements can be identified by conducting a careful assessment, particularly in those high-risk patients preoperatively. Those with abnormalities need to be closely monitored in the preoperative, perioperative, and postoperative periods. If abnormalities are detected, aggressive management can then proceed promptly. Plasma urea and electrolytes should be checked daily. Severely ill patients with abdominal infection, sepsis, fistulas, and extensive burns are more likely to sustain significant problems of fluid balance and malnutrition. Therefore, in these patients, maintenance of intravascular volume needs to consider the multiple areas for volume loss, including:

- Replacement perioperative fluids
- Providing maintenance fluids
- Replacement of any ongoing blood losses
- Replacement of insensible losses
- Replacement of third-space losses

The metabolic responses to anesthesia and surgical stress can have profound implications for the patient in the perioperative and postoperative periods.

In this context, third-space losses refer to the sequestration of fluids in a nonfunctional extracellular space or fluid shifts into a body cavity (transcellular space), such as ascites and pleural effusion. Quantifying perioperative third-space fluid loss is difficult, and estimation tools are inexact. Reestablishing normal perfusion is more critical than replacing a calculated fluid loss.

To reduce the stress and the metabolic effects of surgery, the following must be considered:

- **Surgical Aspects**
  Reduce primary surgical injury and blood loss.

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> *Reestablishing normal perfusion is more critical than replacing an arbitrary estimation of third-space fluid loss.*
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- **Anesthetic Aspects**
  Attention to individualized control of a patient’s physiology during surgery optimizes outcomes. Care in the administration of analgesia needs to be considered with the aim of reducing total opioid use to avoid the risk of decreased respiratory drive and ileus. The management of fluids needs to be individualized to maintain cellular perfusion, reduce extracellular fluids flux, and prevent salt and water overload, which can lead to cardiac dysfunction, pulmonary edema, and tissue fluid accumulation.

- **Postoperative Goals**
  By encouraging early gut function and enteral feeding, the patient achieves these benefits: hormonal effects of duodenal feeding, maintenance of gut perfusion, reduced surgical insult, avoidance of nasogastric tubes, and regular quantities of nutrition. Early mobilization to minimize complications, such as chest infection and deep vein thrombosis/pulmonary embolism, stimulates muscle function to maintain strength and reduce insulin resistance.

III. PERIOPERATIVE CHANGES IN THE POSTOPERATIVE SURGICAL PATIENT

A. Postoperative Surgical Patient

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Patients in the immediate postoperative period are subject to disorders in normal respiratory, cardiac, homeostatic, and autonomic function.

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The postoperative surgical patient emerging from anesthesia is subject to derangements in respiratory and cardiac physiology, temperature regulation, coagulation, and autonomic function. It is imperative on receiving the patient from the operating room to rapidly assess the patient's hemodynamic stability, ongoing fluid losses (urine output, surgical drains, nasogastric tube, evidence for bleeding, etc.), mental status, respiratory status, and neuromuscular function. Hypotension may have several causes, including residual cardiovascular depression from inhalational anesthetics (these agents cause vasodilation and myocardial depression in a dose-dependent fashion), hypovolemia, hemorrhage, and autonomic dysfunction after reversal of neuromuscular blockade. Spinal and epidural anesthesia can also cause hypotension. The patient's medical history, details of the surgical procedure, and anesthesia record of the medications and fluids administered can point the clinician toward the cause for hemodynamic derangements. Physical examination of the patient is often helpful. Important considerations regarding the postoperative surgical patient are listed in **Table 2-1**.

Table 2-1 Considerations When Examining a Postoperative Surgical Patient

- Does the patient exhibit pallor, distal cyanosis, or poor capillary refill (greater than 2 seconds for color to return to a digit on manual compression)?
- Is the patient dependent on vasopressors or continued fluid administration for adequate blood pressure?
- Review of any laboratory work obtained intraoperatively and/or a blood gas with electrolytes and a complete blood count and serum lactate may be invaluable.
- If a large amount of blood products were administered intraoperatively, the patient may have profound hypocalcemia because of the large amounts of citrate, which chelates ionized calcium. (The ionized calcium level is the biologically active form and is the most clinically helpful in assessing a calcium deficit).
- A patient with a significant metabolic acidosis and a low pH may be less responsive to vasopressor and/or inotropic agents.
- Transfusion of large amounts of packed red blood cells may also be associated with hyperkalemia. Concerning transfusion in an anemic patient, most national criteria subscribe to a restrictive strategy with a hemoglobin of 7 g/dL or a hematocrit of roughly 21%. An exception to this may be in patients with known coronary disease who have had a recent myocardial infarction, cardiac surgery, or vascular surgery. In these patient populations, a transfusion threshold of hemoglobin of 8 g/dL or higher may be more appropriate.

B. Blood and Blood Product Transfusion

Several reasons exist for a restrictive transfusion practice. One reason is the low risk of viral infectious disease transmission. Other significant complications of transfusion include volume overload, acute hemolytic transfusion reaction (rare), transfusion-related acute lung injury (TRALI), and very importantly, suppression of the immune system.

The storage of red blood cells results in decreased levels of 2,3-diphosphoglycerate (2,3-DPG), which results in a leftward shift in the oxygen-hemoglobin dissociation curve. This results in the transfused red blood cells more avidly binding oxygen with diminished oxygen transport to potentially ischemic tissues.

Patients may be coagulopathic following surgery, especially if the surgery was prolonged, there was significant blood loss or volume shifts, the patient sustained massive trauma, or the patient is septic or has systemic inflammatory response syndrome (SIRS). It may be prudent to check a platelet count, prothrombin time (PT), international normalized ratio (INR), partial thromboplastin time (PTT), fibrinogen level, and titer of fibrin split products (FSP). Some institutions use viscoelastic testing technology (such as thromboelastography or rotational thromboelastometry), which gives a broad overview of the coagulation cascade and allows specific deficiencies to be identified and corrected. The pH and temperature of the patient should also be aggressively monitored because severe derangements in these parameters may profoundly affect the coagulation cascade in the absence of any abnormalities in laboratory measurements of hemostasis. In response to recent evidence regarding transfusion practices in massive blood loss, the use of crystalloid solutions has diminished.

In contrast, the use of a 1:1:1 ratio for the transfusion of packed red blood cells, fresh frozen plasma, and platelets in patients requiring massive transfusion has been associated with better outcomes. This has resulted in less third spacing of fluids, a more rapid return of intestinal function, and better overall clinical outcomes. Transfusion of large volumes of crystalloid solutions, especially normal saline, in patients who sustained significant hemorrhagic shock results in a dilutional coagulopathy, hyperchloremic metabolic acidosis, an increased risk of acute kidney injury, and poorer outcomes.

C. Respiratory Status

A respiratory status of a patient in the perioperative period is also of concern. If the patient is extubated, look for evidence of fatigue, a rapid shallow respiratory rate, use of accessory respiratory muscles, and the patient's level of consciousness. An agitated patient gasping for air or a somnolent patient who is difficult to arouse may both require reintubation. This a clinical decision that does not require an arterial blood gas. Assess the patient's skin color:

- Is there evidence of cyanosis?
- Is the patient intubated?
- If so, what are the ventilator settings?

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Specific complications related to the effects of anesthesia, as well as the interaction with the patient's routine medication regimen and disease processes, must be considered in the perioperative period.

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Difficulties with oxygenation or hypoxemic respiratory failure may arise as a result of fluid overload, acute respiratory distress syndrome, or congestive heart failure. Acute respiratory distress syndrome may have many etiologies in the perioperative period, including aspiration of gastric contents (often on induction), soiling of the peritoneum with enteric contents resulting in sepsis, transfusion-related lung injury, or systemic inflammatory response syndrome resulting from severe traumatic injury. Bedside thoracic echocardiography may help distinguish cardiogenic from noncardiogenic causes of increased lung water. Hypercapnic respiratory failure may result from splinting from pain following a thoracic or high abdominal incision, from exacerbation of underlying chronic obstructive pulmonary disease or asthma, or from the residual effects of opioids or inhalational anesthetics. It has been shown in healthy volunteers that even subanesthetic concentrations of inhalational anesthetic gas alter the ventilatory response to hypercarbia and hypoxemia.

D. Effects of Anesthesia and Drug Interactions

1. Drug Interactions

The potential for drug interactions and idiosyncratic reactions is a genuine possibility, given the number of medications administered to a surgical patient in the perioperative period and medications that the patient may be taking for preexisting medical conditions before the surgical procedure. A surgical patient may typically receive an antibiotic (perhaps two or three), an anxiolytic (benzodiazepine), opioids, non-opioid analgesics, muscle relaxants, antiemetic agents, possibly vasoactive agents (either vasopressors, anticholinergics, vasodilators, beta-blockers, etc.) as well as a reversal for muscle relaxation if extubation is planned. An elevated temperature in the postoperative period may have many causes, including malignant hyperthermia, malignant neuroleptic syndrome, central anticholinergic syndrome, and the serotonin syndrome. Drug interactions with anesthetic agents cause many of the toxidromes mentioned previously.

2. Serotonin Syndrome

This is a clinical entity usually caused by the interaction of two or more medications, which increase the levels of serotonin in the body. Many antidepressants are serotonin reuptake inhibitors, and these may interact with other drugs typically given in the perioperative period (which also increases serotonin levels), including meperidine, ondansetron, metoclopramide, and tramadol. A range of symptoms from mild to severe may occur, including agitation, elevated temperature, diaphoresis, dilated pupils, and tremor. Complications of severe temperature elevation can occur, including seizures and rhabdomyolysis. A patient may be using recreational substances such as ecstasy (MDMA), cocaine, or amphetamines, which will also cause serotonin levels to be elevated. Management of these patients involves discontinuation of the responsible drugs, treating agitation with benzodiazepines as appropriate, and using active cooling measures to bring the patient's body temperature to a normal range. Some clinicians have advocated for the use of serotonin antagonists, such as cyproheptadine, which must be administered enterally. Depending on the type of surgical procedure that the patient underwent, this may or may not be feasible.

3. Malignant Hyperthermia

This is a very rare but feared complication of general anesthesia. It is known to have a genetic component, with familial expression, but spontaneous cases have also been reported. Exposure of a susceptible patient to triggering agents known to cause this clinical entity can result in muscle rigidity, hypercarbia, tachycardia, hypertension, severe temperature elevation, hyperkalemia, mottling of the skin, and cyanosis. The most commonly known triggering agents are succinylcholine and inhalational anesthetics (halothane, isoflurane, desflurane, etc.). Because of abnormalities caused by these triggering agents, increased intracellular calcium builds up in the muscle of these patients, causing prolonged contraction and consumption of adenosine triphosphate. Treatment consists of stopping exposure to the triggering agents (inhalational anesthetics), actively cooling the patient, and administration of dantrolene. If a patient manifests an episode of malignant hyperthermia, family members should be tested for this condition because inheritance is often in an autosomal-dominant fashion.

4. Malignant Neuroleptic Syndrome

This is a manifestation of antipsychotic drug toxicity, which may mimic malignant hyperthermia. Malignant neuroleptic syndrome presents with altered mental status, muscular rigidity, hyperthermia, and autonomic dysfunction. Generally, younger males who have recently begun treatment with tranquilizers, such as the butyrophenones (haloperidol) or the phenothiazines (chlorpromazine, fluphenazine), are the population at risk for this condition, especially with high doses of these drugs or dehydration. Treatment in the postoperative period with the antiemetic metoclopramide may exacerbate this condition. Most antipsychotic drugs require dopamine antagonism for their clinical effect, and this is the mechanism thought to produce this syndrome. Treatment is supportive with the termination of the precipitating drug, active cooling with ice water immersion for severe hyperthermia (temperature > 41°C [106°F]), rehydration, administration of benzodiazepines and/or muscle relaxants to control muscle rigidity, and administration of bromocriptine in doses of 2.5 to 10 mg three times a day.

5. Central Anticholinergic Syndrome

This is another clinical entity that can be seen in the postoperative period as a result of drug interactions. Tricyclic antidepressants, antihistamines, antiparkinsonian drugs, and pharmacologic agents used to treat schizophrenia may interact with medications such as scopolamine, atropine, or glycopyrrolate to produce a syndrome with agitated delirium, hyperthermia, and seizures. Physostigmine administered intravenously may cause rapid resolution of mental status changes and be diagnostic at the same time. This agent is a tertiary amine and is therefore uncharged, which allows it to cross the blood-brain barrier. Thereafter, it reversibly binds to acetylcholinesterase and prevents the degradation of acetylcholine in the central nervous system. This enables the neurotransmitters to accumulate and competitively reverse muscarinic receptor inhibition. Active cooling measures for hyperthermia and benzodiazepines for agitated delirium may also be helpful.

6. Medication Reversal

If a patient has been given muscle relaxants (vecuronium or rocuronium) to facilitate surgery, it is imperative to ensure that their effects are reversed or are no longer present at the end of the procedure if tracheal extubation is planned. Patients should be assessed for the ability to follow commands, a strong hand grip, the ability to hold their head up for 5 seconds, and being able to generate a forced vital capacity of 10 to 12 mL/kg. It is advisable to reverse short- or intermediate-acting muscle relaxants. Incomplete reversal of neuromuscular paralysis manifests as uncoordinated muscle movements (“fish out of water”), agitation and weak handgrip. Hypercarbia, hypocalcemia, and hypermagnesemia appear to exacerbate the situation as does the presence of an underlying neuromuscular disorder (multiple sclerosis, myasthenia gravis). Any doubt about a patient’s muscle strength should preclude tracheal extubation until baseline muscular function has returned.

Occasionally, a patient may present with an altered mental status and prolonged emergence from anesthesia. A careful review of the medications administered during surgery, the patient’s medical history, baseline vital signs, baseline electrolytes, and concomitant medications may offer clues regarding the etiology of a significant delay to consciousness. Overmedication with benzodiazepines and/or opioids are common and can usually be addressed with their respective reversal agents (flumazenil and naloxone).

7. Medication History

If a patient was known to have hypertension, what was the baseline blood pressure before the start of surgery? A patient with a baseline blood pressure of 140/90 mm Hg who had blood pressures of 90/60 mm Hg intraoperatively may be at risk for cerebral ischemia and infarction. Was the patient hypothyroid and taking a supplement? When was the last time the patient received his or her thyroid medication? A history of illicit substance use may contribute to the clinical picture. Finally, consultation with a neurologist, especially if there is concern about an underlying seizure disorder, may be helpful.

8. Regional Anesthesia

For patients undergoing surgical procedures on the lower abdomen or the lower extremities, regional anesthesia with either a spinal or epidural technique is often chosen. When neuraxial anesthesia is employed, the clinician should be aware of the cardiorespiratory changes that usually take place. Three sets of nerves, the autonomic, sensory, and motor, are affected with the autonomic being the most sensitive to blockade with local anesthetic and the motor being the least sensitive. Hypotension and bradycardia mimicking shock caused by spinal cord trauma may occur if the level of the spinal blockade spreads in a cephalad direction to include the cardioaccelerator fibers, which are located in thoracic dermatomes T2 to T4. This may require the use of intravenous sympathomimetic agents, such as ephedrine, and volume loading with crystalloid solutions to counteract the vasodilation seen with blockade of the sympathetic nervous system. These hemodynamic changes are temporary and resolve as the agent injected into the cerebral spinal fluid or epidural space dissipates (usually in the case of bupivacaine, this is 2 or 3 hours). If there is significant cephalad spread of local anesthetic into the thoracic dermatomes, the intercostal muscles may be affected. Most patients tolerate this well; however, those with diaphragmatic dysfunction (hyperinflated lungs seen in emphysema and chronic bronchitis) may have respiratory embarrassment. If the level of the neuraxial blockade inadvertently rises to the cervical dermatome, the patient may not be able to breathe because diaphragmatic function is now affected. This is commonly referred to as a high spinal and requires the clinician to either take over respiration with mask ventilation or to secure the airway with an endotracheal tube.

IV. SURGICAL IMPLICATIONS FOR THE IMMEDIATE POSTOPERATIVE PERIOD

Patients who have undergone surgical procedures have many commonalities, but also significant differences based on the specific procedure performed. In general, once the effects of anesthetic agents have subsided, patients should have a reasonably quick return to normal cardiovascular physiology. When this is delayed, or when there are new abnormalities that develop, the immediate concern should be for a complication related to the surgical procedure. However, exacerbation of a comorbid condition or the development of a new perioperative complication may also be taking place. Rapid differentiation between these issues is essential to allow for appropriate and timely intervention.

In general, immediate postoperative complications can be broken down into one of several relevant categories. We will examine each category independently to identify the immediate surgical and nonsurgical interventions.

A. Postoperative Respiratory Failure

In general, the development of new postoperative respiratory failure can have a wide variety of causes and may be multifactorial. Once immediate issues, such as respiratory depression caused by narcotic analgesia or persistent neuromuscular blockade, have been ruled out, it is crucial to search for other causes of postoperative respiratory decline. One important consideration is the patient's comorbidities before the surgical procedure. Does the patient have preexisting chronic obstructive pulmonary disease or congestive heart failure? If so, workup and treatment can commence as usual. Was the patient immobile or otherwise at high risk for venous thromboembolism or pulmonary embolism?

Postoperative respiratory failure has many causes, from simple atelectasis to aspiration to massive pulmonary embolism, and any workup must consider the broad differential involved as well as the specific surgical procedure involved. One important consideration is inadequate postoperative pain control leading to splinting. Although patients with chest or upper abdominal surgery are at the highest risk, it is essential to assess the patient's respiratory effort and, if significant splinting as a result of pain is occurring, reevaluate the postoperative pain regimen. The increasing use of neuraxial anesthesia for high-risk procedures can significantly decrease the likelihood of suboptimal pain control in the immediate postoperative period, with a decrease in the potential respiratory complications.

One important consideration is postoperative respiratory failure in the patient who has undergone a bowel resection and anastomosis. In addition to other causes, it is important to include intraabdominal sepsis secondary to a bowel leak or anastomotic breakdown in the overall differential. Although these complications are typically delayed for several days, to miss one of these complications results in devastating implications for the patient.

B. Postoperative Hypotension

There are many root causes of postoperative hypotension. However, in the postoperative patient, the obvious risk above and beyond the other reasons is severe postoperative anemia or acute bleeding. Understanding the basics of the intraoperative course is essential in early diagnosis and management. Important immediate considerations include:

- Did the patient have excessive intraoperative blood loss?
- If a bowel anastomosis was performed, could the patient be bleeding from the anastomosis within the gastrointestinal tract?
- Was the procedure exceptionally long, possibly placing the patient at risk for hypovolemia because of increased insensible losses?
- What was used to correct the patient's volume status?
- If excessive crystalloid or exclusively packed red blood cells were used, could the patient be at risk for coagulopathy? Significant coagulopathy may place the patient at risk for postoperative bleeding.
- If the patient has drains in the surgical field, what is the amount and character of the drainage, and has it changed significantly in the postoperative period?
- If a significant risk for hypovolemia exists, a gentle fluid challenge may be indicated. If there is concern for coagulopathy, traditional coagulation laboratory tests (PT/PTT/INR/fibrinogen) or viscoelastic testing should be obtained and any abnormalities aggressively corrected. If critical and symptomatic anemia exists, transfusion of packed red blood cells should

be initiated. An immediate severe and progressive anemia may not accompany acute hemorrhage until volume resuscitation is begun.

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Postoperative hypotension should raise the concern for possible bleeding as well as the consideration for other sources, such as sepsis or effects of neuraxial anesthesia.

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1. Cardiogenic Source

Postoperative hypotension of a cardiogenic origin can be more ominous. Perioperative myocardial ischemia and infarction can present with a wide variety of symptoms, from classic crushing substernal chest pain to cardiac arrhythmia, asymptomatic hypotension, and sudden cardiovascular collapse, or they may be completely asymptomatic. Surgical patients are also prone to silent myocardial ischemia given their potential altered mental status, comorbidities including diabetes mellitus, and distracting pain from surgical incisions. Maintaining a high index of suspicion is essential to allow for early diagnosis and management. In the early postoperative period, the management of cardiac ischemia is complicated by the potential risk of bleeding if aggressive anticoagulation and antiplatelet therapy are warranted. Close communication with the surgical team is essential to weigh the risks of bleeding versus the benefits of early reperfusion and salvage of at-risk myocardium. Although in some patients, such as those who underwent a neurologic or spinal procedure, any postoperative bleeding may be problematic; in others, the true potential risk from postoperative hemorrhage may be somewhat minimal. Another rare consideration is Takotsubo or catecholamine/stress-induced cardiomyopathy. Although the presentation may mimic that of acute myocardial ischemia and infarction, including symptoms such as heart failure and arrhythmias, no occlusive lesion is seen on coronary angiography. Care is typically supportive in nature, with the judicious use of vasopressors and inotropic agents. Early recognition and aggressive management are important because perioperative myocardial infarction carries a greater risk for mortality than a similar event in a medical patient.

2. Neuraxial Analgesia

A critical consideration regarding postoperative hypotension is the use of neuraxial analgesia. Patients with spinal or epidural anesthesia may experience vasodilation with relative hypovolemia because of the anesthetic effects. The hypotension will generally respond well to a decrease or discontinuation of the anesthetic agent; however, volume resuscitation or occasionally short-term use of vasopressors is sometimes needed to maintain tissue perfusion until the anesthetic is fully metabolized.

3. Vasopressor Use

It is crucial to consider the implications of vasopressor use in the immediate postoperative patient. Although vasodilatory shock secondary to sepsis is undoubtedly on the differential for hypotension, especially in surgical cases involving massive contamination or when preoperative sepsis/systemic inflammatory response syndrome already existed, caution should be used in assuming that it is the only cause of hypotension that exists. In the postoperative patient, any significant increase in vasopressor requirements should prompt an evaluation for hypovolemia or acute hemorrhage. Using vasopressors when the underlying cause of hypotension is hypovolemia is undesirable. The vasoconstriction may increase blood pressure, worsen tissue perfusion, and lead to a higher risk of organ failure and worse outcomes. Vasopressors may potentially place any bowel anastomosis at an increased risk of breakdown. Restoring intravascular volume should be the primary goal in the resuscitation of the hypovolemic patient with the judicious use of vasopressors if necessary.

C. Abdominal Compartment Syndrome

For patients undergoing abdominal surgery, especially in cases complicated by perforation or requiring significant resuscitation, a concern in the patient with progressive respiratory and hemodynamic instability is abdominal compartment syndrome (**Chapter 14**). Patients at risk include those with severe injuries, complex abdominal surgical procedures, and the need for large-volume resuscitation. The use of appropriate damage control techniques can significantly decrease the risk of postoperative abdominal compartment syndrome. These techniques are further described in **Chapter 3**. Early involvement of the surgical team is essential if developing compartment syndrome is suspected.

D. Wound Infections

> *Surgical wound infections, while typically presenting in a delayed fashion, can appear hours after a surgical procedure and be rapidly progressive.*

One of the most common nosocomial infections involves surgical wound infections and resulting complications. The specific risk is highly dependent on the specifics of the surgical procedure involved, including the presence of significant contamination at the time of the initial surgical intervention, the particulars of the surgical procedure performed, as well as the surgical wound classification (**Table 2-2**). Although infection rates of 1% to 3% occur in clean wounds, the rate may be as high as 40% in cases involving gross contamination. Surgical wound infections usually present in a somewhat delayed fashion, starting 5–6 days after the surgical procedure and persisting up to 30 or more days, and are not typically a concern in the immediate postoperative period. However, rarely a surgical wound will develop an infection of an invasive and aggressive pathogen such as clostridia species and certain streptococcal species. In these cases, significant symptoms can develop within hours of the index surgery or injury. These infections are characterized by rapid progression and require early and aggressive surgical management, including early wound opening with aggressive debridement as well as antibiotic therapy. Any significant delay in the identification and intervention of these rare infections will place the patient at substantial risk.

Table 2-2 Surgical Wound Classifications

Class I	Clean	Uninfected wound. No entry into the respiratory, alimentary, genital, or urinary tract.
Class II	Clean Contaminated	Respiratory, alimentary, genital, or urinary tract entered under controlled conditions. No unusual contamination.
Class III	Contaminated	Open, fresh, accidental wounds. Major break in sterile technique, gross spillage from the gastrointestinal tract, incisions through areas with acute non-purulent inflammation.
Class IV	Dirty	Old traumatic wounds with devitalized tissue. Perforated viscus. Purulent peritonitis. Gross infection or abscess.

Data taken from the American College of Surgeons and CDC criteria on Surgical Wound Classifications

E. Venous Thromboembolism

Although guidelines for some high-risk procedures recommend initiation of chemical prophylaxis for venous thromboembolism (VTE) in the preoperative setting, most elective surgical patients have deep vein thrombosis (DVT) prophylaxis initiated postoperatively, which might leave them at risk for the development of interoperative VTE or pulmonary embolism. For patients hospitalized before their surgical procedure, guidelines regarding chemical prophylaxis for VTE should be followed. When performing urgent or emergent surgical procedures in this population, the decision to continue or withhold chemical prophylaxis for DVT before the surgical procedure depends on multiple factors, including the bleeding risk of the specific procedure performed as well as the type of anesthesia being used. For patients undergoing high-risk procedures, especially intracranial or spine procedures, in which even a small postoperative bleed might have devastating complications, it is generally advisable to withhold preoperative chemical prophylaxis for DVT. However, for many other surgical procedures, the current trend is to continue chemical prophylaxis for DVT throughout the procedure. It is essential to discuss with the surgical team the timing and safety for the initiation of postoperative chemical prophylaxis for DVT. However, if neuraxial anesthesia (spinal, epidural) is used, it may be necessary to withhold chemical prophylaxis or use a different form, such as unfractionated heparin, which may be somewhat less effective, albeit with a lower risk of bleeding.

V. OPERATING ROOM SUMMARY AND CRITICAL HANDOFF INFORMATION

A. Handoff Process

Modern surgical procedures offer improvements in quality and duration of life. Through that process, surgical patients experience multiple transitions in care. This is especially true of surgical patients who will be cared for by numerous providers in a variety of physical locations as they progress from preoperative areas, through the operating room, and then to the intensive care unit.

Studies of the transition of care within hospitals, and specifically, the transition from the operating room to the intensive care unit, had demonstrated an association with adverse events. These changes in location, environment, and caregivers have parallels to processes in commercial aviation, nuclear power, and professional racing. Application of successful communication and teamwork processes from these industries have been integrated into anesthesia and surgery with resultant reductions in complications.

The handoff process, also known as the handover process, typically involves multiple providers, information of high complexity and volume, and patients with rapidly evolving physiology. Effective communication and teamwork are essential elements of a successful transition from the operating room to the intensive care unit for the critically ill or injured patient. Patients are especially vulnerable when they cannot participate in the handoff process because of sedation or anesthesia. Numerous studies have demonstrated the negative impact that ineffective or absent patient handoffs have on outcomes. Both qualitative and quantitative investigations of the handoff process have identified omissions in the transfer of key information, concerns regarding the volume of data (either too comprehensive or too brief), and general dissatisfaction with the handoff process. Investigators are exploring the communication and teamwork dynamics that contribute to both errors and successes with this process. Several authors have described efforts to quantify the quality of the handoff process as well as the communication methods which transmit the information. Providers giving and receiving handoffs are generally more satisfied with the process when a checklist or script is used, also reporting fewer errors. Observational trials of handoffs using a checklist or script consistently demonstrated fewer errors in the handoff, both in the number of critical items omitted as well as the accuracy of information being conveyed.

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Effective communication during handoffs in the postoperative period is essential for providing safe care by all team members involved.

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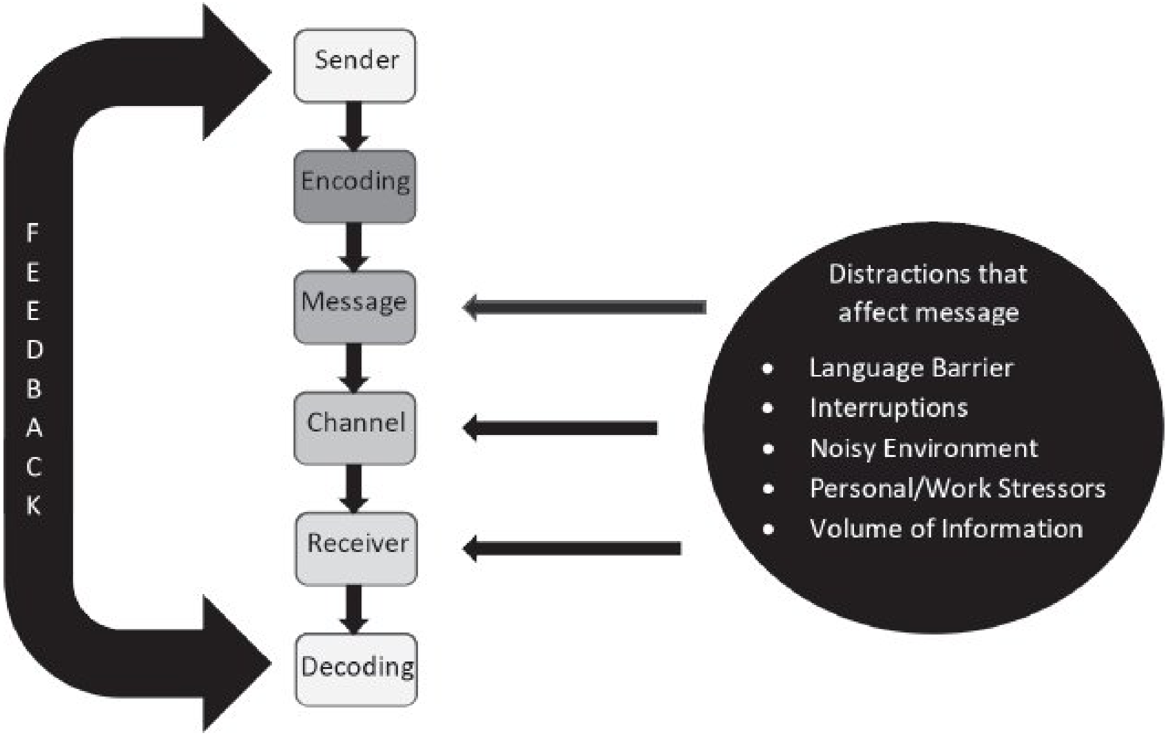
Even established and effective handoff processes can benefit from introspection and self-evaluation. Having providers familiar with team dynamics, crisis management communication, and perioperative care, and observing established processes during real-time handoffs using validated assessment tools can provide beneficial information and feedback. Providers participating in the handoff process should also be queried as to their perceptions of handoff effectiveness and quality.

Outcomes of these investigations should be used to develop and refine handoff processes with a plan for ongoing reevaluation to ensure sustained positive change.

B. Communication Process

Providers involved in the handoff process often have multiple responsibilities competing for their attention. Interruptions are a frequent occurrence in all aspects of medical care. Prominent patient safety organizations have advocated for using a 'Time-Out' process before invasive procedures and surgeries. At that moment, providers cease activity unrelated to the time-out process. The room is silent, like the sterile cockpit concept observed by airline pilots during the takeoff process. Information is confirmed and read back by other providers analogous to the methods used in nuclear submarines. Other providers in the immediate area should demonstrate respect for the importance of information being transferred and avoid interruptions during the handoff. Because the innate attention span of adults engaged in intensive activity is typically limited, the handoff should remain focused to allow maximum attention from both senders and recipients. **Figure 2-1** illustrates the communication flow and elements that degrade the handoff (distractions) and improve handoff (feedback).

Figure 2-1. Elements of Effective Communication Flow


FEEDBACK
Sender
Encoding
Message
Channel
Receiver
Decoding
Distractions that affect message
Language Barrier
Interruptions
Noisy Environment
Personal/Work Stressors
Volume of Information

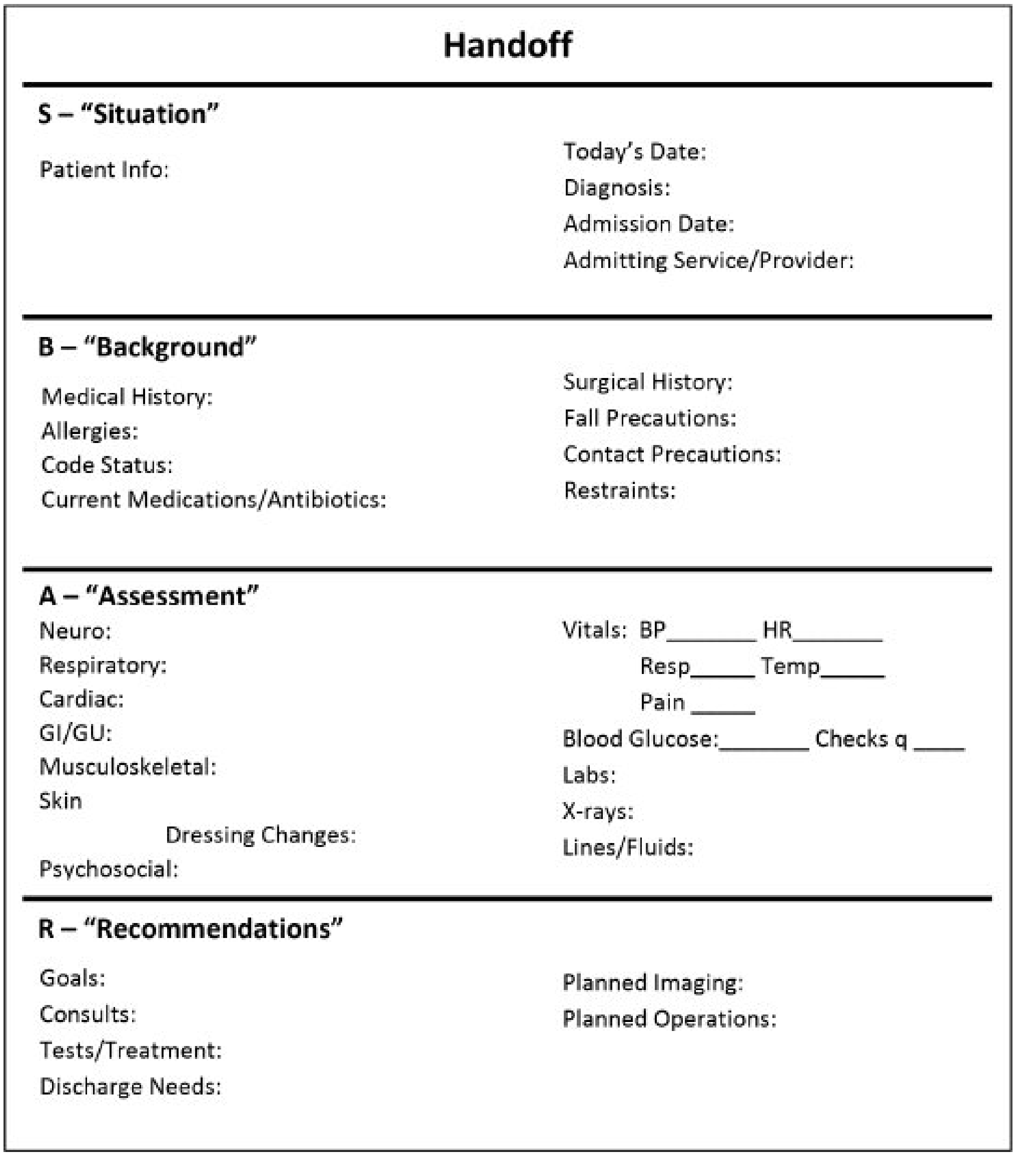
To facilitate an effective handoff process, it is vital to identify the major players involved, including the messengers, the recipients, and the information to be conveyed. Each messenger and recipient have essential elements that must be accurately conveyed to allow for the continuation of safe postoperative care in the intensive care unit (**Table 2-3**).

Table 2-3 Major Players and Considerations in the Handoff Process

Messengers:	Anesthesia	• Focus on airway management, oxygenation, and ventilation parameters, hemodynamic monitoring and medications, vascular access, and monitoring • Induction/intubation/extubation • Intraoperative events • Hemodynamic monitoring • Medications including analgesia, sedation, vasopressors, antibiotics, anticoagulants, and antiplatelet agents
	Surgeon	• Discusses surgical case, complications, blood loss, postoperative surgical care • Reviews patient medical history, medications • Procedure performed • Indication for procedure • Expected and unexpected findings • Postoperative goals • Activity/weight-bearing restrictions
	Circulating Nurse	• Reviews medications and allergies • Reviews social issues • Reviews skin integrity, wound care • Blood glucose and other point-of-care testing • Family liaison • Wounds/devices/drains • Venous/arterial lines • Medical history/chronic medications
	Perfusionist	• Extracorporeal membrane oxygenation /cardiac bypass-related management and events
Recipients:	Bedside Nurse	• Providers working in the ICU are not only accepting the patient; they receive information, equipment, and, most of all, responsibility for the patient. This requires active listening, confirming data that are reported, and making inquiries if any elements of a handoff checklist are omitted.
	Respiratory Therapist	
	Intensivist	

Providers have unique perspectives and biases based on their role in patient care, which can impact the effectiveness of communication and accuracy of information being conveyed. The use of a standardized and scripted format for postoperative handoffs (**Figure 2-2**, **Figure 2-3**) has been shown to reduce errors. Within the script, each provider understands the information that must be conveyed to achieve effective handoff. Beyond the transfer of information, the method of communication is of equal or greater importance. Assigning specific responsibilities for which providers communicate information will be unique to each institution.

Figure 2-2. SBAR Handoff (Situation, Background, Assessment, Recommendation)



Handoff

S – "Situation"

Patient Info:

Today's Date:
Diagnosis:
Admission Date:
Admitting Service/Provider:

B – "Background"

Medical History:
Allergies:
Code Status:
Current Medications/Antibiotics:

Surgical History:
Fall Precautions:
Contact Precautions:
Restraints:

A – "Assessment"

Neuro:
Respiratory:
Cardiac:
GI/GU:
Musculoskeletal:
Skin
Dressing Changes:
Psychosocial:

Vitals: BP_______ HR_______
Resp_____ Temp_____
Pain _____
Blood Glucose:_______ Checks q ____
Labs:
X-rays:
Lines/Fluids:

R – "Recommendations"

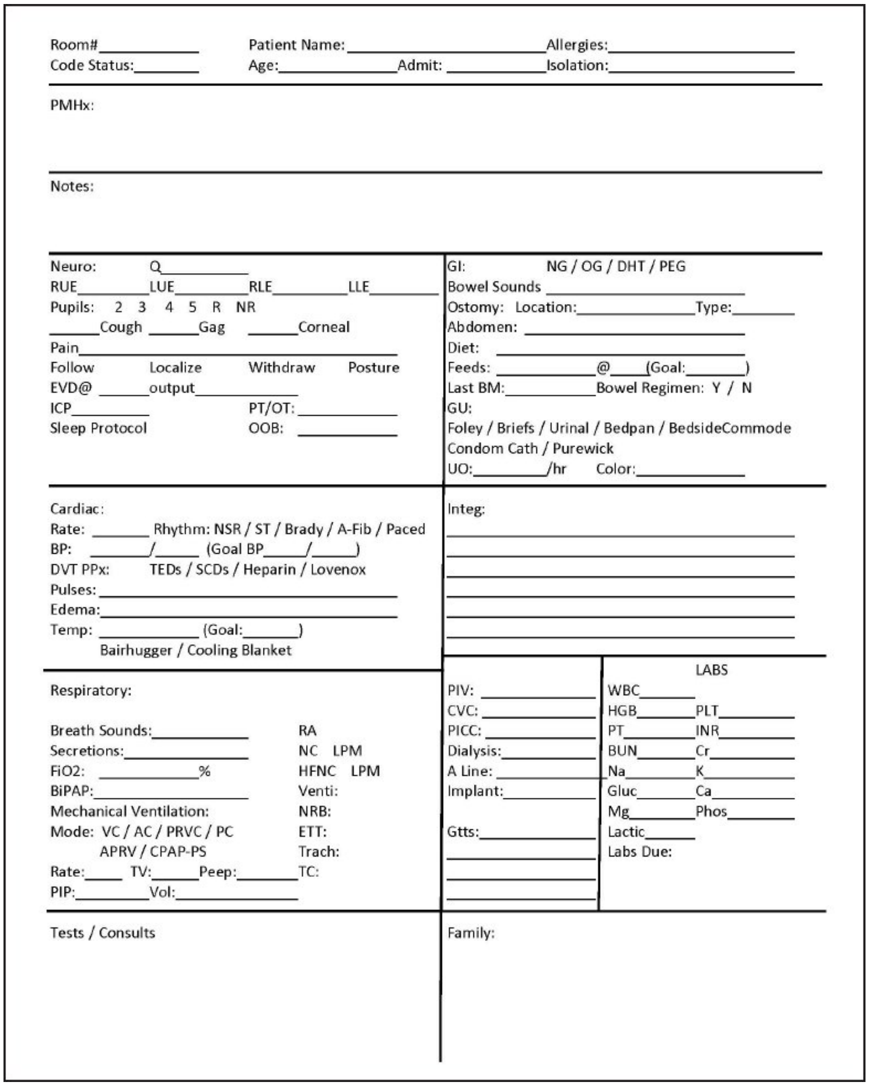
Goals:
Consults:
Tests/Treatment:
Discharge Needs:

Planned Imaging:
Planned Operations:

One study compared the handoff process to a pit-stop for a Formula-1 racing team. Although each team member has specific responsibilities, it is necessary for the entire team to be aware of other members' responsibilities so that processes can be refined with the greatest efficiency. Further, each member learns to communicate verbally and nonverbally to share essential information in a timely fashion. Essential equipment, tires, and fuel must be handled properly to avoid injury or malfunction.

Finally, the process must be accomplished quickly, 7 seconds on average, to minimize interruption of road racing. Many parallels exist between the pit-stop and the handoff, including team integration of skill sets, effective communication, brevity to allow ongoing workflow, and safe handling of the patient and equipment. A mature, organized, and sustainably implemented handoff process will yield positive results for patients, providers, and institutions.

Figure 2-3. Handoff/Handover Template



Room#______ Patient Name:__________ Allergies:__________
Code Status:______ Age:______ Admit:______ Isolation:__________

PMHx:

Notes:

Neuro: Q______
RUE______ LUE______ RLE______ LLE______
Pupils: 2 3 4 5 R NR
______Cough ______Gag ______Corneal
Pain__________
Follow Localize Withdraw Posture
EVD@ ______output______
ICP______ PT/OT:______
Sleep Protocol OOB:______

GI: NG / OG / DHT / PEG
Bowel Sounds __________
Ostomy: Location:______ Type:______
Abdomen: __________
Diet: __________
Feeds: ______@____(Goal:______)
Last BM:______ Bowel Regimen: Y / N
GU:
Foley / Briefs / Urinal / Bedpan / BedsideCommode
Condom Cath / Purewick
UO:______/hr Color:______

Cardiac:
Rate: ______ Rhythm: NSR / ST / Brady / A-Fib / Paced
BP: ______/______ (Goal BP____/____)
DVT PPx: TEDs / SCDs / Heparin / Lovenox
Pulses:__________
Edema:__________
Temp: ______ (Goal:______)
Bairhugger / Cooling Blanket

Integ:

Respiratory:

Breath Sounds:______ RA
Secretions:______ NC LPM
FiO2: ______% HFNC LPM
BiPAP:______ Venti:
Mechanical Ventilation: NRB:
Mode: VC / AC / PRVC / PC ETT:
APRV / CPAP-PS Trach:
Rate:____ TV:____ Peep:____ TC:
PIP:______ Vol:______

PIV: ______
CVC: ______
PICC: ______
Dialysis:______
A Line: ______
Implant:______
Gtts:______

LABS
WBC______
HGB______ PLT______
PT______ INR______
BUN______ Cr______
Na______ K______
Gluc______ Ca______
Mg______ Phos______
Lactic______
Labs Due:

Tests / Consults

Family:

VI. CONCLUSION

As stated previously, the critically ill postoperative patient requires attention to multiple potential areas of concern. Although a surgical complication requiring emergent reoperation may be occurring, other aspects of patient care, including anesthetic complications, medical complications, or exacerbation of existing comorbidities, might also require immediate attention. Immediate evaluation and aggressive intervention are critically important to rapidly diagnosis and intervene as necessary. Care providers from multiple disciplines need to work together, ensuring that the entire team is aware of critical information to ensure good patient outcomes.

Case Study

Over the next 60 minutes, the patient has a progressive decline with worsening hypoxia, increasing peak airway pressures, decreasing urine output, and worsening hypotension. The crystalloid resuscitation that was started in the operating room continues, and he receives an additional 4 liters of normal saline without any improvement in his hemodynamics or urine output. His vasopressor requirements continue to increase, requiring 20 μg/min of norepinephrine and 0.03 units/min of vasopressin to maintain a mean arterial pressure (MAP) of 55 mm Hg. Dynamic monitoring is initiated with a high pulse pressure variation, and an abdominal ultrasound demonstrates free fluid as well as a collapsible inferior vena cava (IVC). Laboratory tests demonstrate a hemoglobin of 5.5 g/dL and a hematocrit of 15%. Blood transfusion is initiated, and the critical care team requests an urgent surgical reevaluation. The patient's abdomen is becoming more distended.

As the surgical team comes to the bedside, bladder pressure is obtained, demonstrating a pressure of 35 mm Hg. The patient is emergently brought back to the operating room for a diagnosis of abdominal compartment syndrome and likely postoperative hemorrhage. At re-exploration, the patient's ventilatory status improves significantly after his abdomen is reopened. Intraoperatively, he is found to have 2.5 liters of intra-abdominal blood with bleeding from a mesenteric vessel as well as a significantly edematous bowel. The bleeding is controlled, the patient is transfused a total of 6 units of packed red blood cells, 5 units of fresh frozen plasma, and 1 unit of pooled platelets. Following the transfusion, his hemodynamics improve significantly, and his vasopressors are weaned. Because of the increased abdominal pressures and significant bowel edema, temporary abdominal closure is performed. On return to the ICU, his hemodynamics are significantly improved. Over the next several days, the patient develops an acute kidney injury, which eventually resolves, and his vasopressors are weaned off. His acute postoperative hypoxic respiratory failure slowly improves. He returns to the operating room several times but eventually undergoes abdominal closure and is extubated.

Key Points

Approach to the Surgical Patient, Part 1

- Multiple physiologic changes occur during surgical procedures affecting the perioperative and postoperative periods.
- Surgical procedures can induce a profound physiologic stress response with a wide range of metabolic responses.
- Attending to specific surgical, anesthesia, and postoperative aspects of care can help limit the surgical stress encountered.
- Cardiovascular instability in the postoperative period could have several causes including the residual effects of anesthesia, hypovolemia, autonomic dysfunction as a result of the reversal of neuromuscular blockade, residual effects of regional anesthesia, or profound hypocalcemia if large amounts of blood products were transfused.
- Profound acidosis may cause a patient to be less responsive to inotropes and vasopressors.
- Significant complications can arise from transfusion of packed red blood cells, including infectious complications, volume overload, acute lung injury, and coagulopathy.
- Because of the multiple classes of drugs administered perioperatively, life-threatening drug interactions can occur, including malignant hyperthermia, malignant neuroleptic syndrome, serotonin syndrome, central anticholinergic syndrome, and incomplete reversal of neuromuscular blockade.
- Respiratory failure in the postoperative period is often multifactorial, including aspects of preoperative comorbidities, anesthesia technique, surgical procedures, and pain control.

- Postoperative hypotension should always prompt an investigation of possible bleeding. As acute hemorrhage is being ruled out, other causes, including perioperative myocardial infarction, must be considered.
- New or increasing postoperative vasopressor needs should prompt an investigation for possible hemorrhage. Adequate volume resuscitation must be ensured.
- Surgical patients are at high risk for VTE, and appropriate prophylaxis using chemical and mechanical techniques should be used for prevention.
- Multiple handoffs during patient care are associated with adverse events and worse outcomes.
- The use of a checklist or script during the handoff process can help ensure adequate transfer of critical information and improve provider satisfaction.
- Each specific provider involved in the care of a patient may have significant and unique information to convey during the handoff process.

Suggested Readings

1. Catchpole KR, de Leval MR, McEwan A, et al. Patient handoff from surgery to intensive care: using Formula 1 pit-stop and aviation models to improve safety and quality. *Paediatr Anaesth*. 2007;17:470-478.
2. Gubler KD, Gentilello LM, Hassantash SA, Maier RV. The impact of hypothermia on dilutional coagulopathy. *J Trauma*. 1994;36:847.
3. Kulaylat MN, Dayton MT. Surgical Complications. In: *Sabston Textbook of Surgery*, 20th ed. Townsend C, Beauchamp RD, Evers BM, Mattox K (eds). Elsevier; 2016.
4. Lane-Fall MB, Beidas RS, Pascual JL, et al. Handoffs and transitions in critical care (HATRICC): protocol for a mixed methods study of operating room to intensive care unit handoffs. *BMC Surg*. 2014;14:96.

5. Mayo NE, Feldman L, Scott S, et al. Impact of preoperative change in physical function on postoperative recovery: argument supporting rehabilitation for colonic surgery. *Surgery*. 2011;150(3):505-514.
6. Scott MJ, Miller TE. Pathophysiology of major surgery and the role of enhanced recovery pathways and the anesthesiologist to improve outcomes. *Anesthesiol Clin*. 2015;33(1):79-91.
7. Moon TS, Gonzales MX, Woods AP, Fox PE. Improving the quality of the operating room to intensive care unit handoff at an urban teaching hospital through a bundled intervention. *J Clin Anesth*. 2016;31:5-12.
8. Nagpal K, Abboudi M, Manchanda C, et al. Improving postoperative handoff: a prospective observational study. *Am J Surg*. 2013;206(4):494-501.
9. Rose DK, Cohen MM, Wigglesworth DF, DeBoer DP. Critical respiratory events in the postanesthesia care unit. Patient, surgical and anesthetic factors. *Anesthesiology*. 1994;81(2):410-418.
10. Veenhof AA, Vlug MS, van der pass MH, et al. Surgical stress response and postoperative immune function after laparoscopy or open surgery with fast track or standardized perioperative care: a randomized trial. *Ann Surg*. 2012;255(2):216-221.

Suggested Websites

1. American Society of Anesthesiologists Standards and Guidelines. www.asahq.org/standards-and-guidelines
2. Ausmed. www.ausmed.com/articles/postoperative-complications
3. World Health Organization. www.who.int/surgery/publications/Postoperativecare.pdf

Chapter 3

APPROACH TO THE SURGICAL PATIENT, PART 2: SURGICAL EMERGENCIES

✓ Objectives

- Recognize the signs and symptoms of a surgical emergency based on the patient's history and clinical presentation.
- Prioritize appropriate treatment and management of a surgical emergency.
- Optimize the use of damage control techniques.
- Employ frailty assessment to stratify perioperative risk.

Case Study

A 70-year-old woman with a history of hypertension, diverticular disease, and atrial fibrillation treated with warfarin presented with abdominal pain, nausea, vomiting, and fever. The patient's computerized tomography (CT) scan revealed perforated diverticulitis, and she subsequently underwent a left sigmoidectomy. On postoperative day one, the patient reports increasing abdominal pain and bloating. Her vital signs are as follows: temperature 38.6°C (101.4°F), blood pressure 99/59 mm Hg, heart rate 110 beats/min, respiratory rate 26 breaths/min, and pulse oximetry 93% on room air. On examination, the patient is confused, tachypneic, and the abdomen is tense, distended, and inappropriately tender to palpation with murky output from the Jackson-Pratt (JP) drain.

- What information is needed to determine whether the patient has a surgical emergency?
- What immediate interventions should be performed?

I. INTRODUCTION

A stratified approach is appropriate for the patient presenting with distress after a surgical procedure. Initial priorities include knowledge of the procedure performed and a high index of suspicion which may be triggered by changes in physical examination. Deterioration in vital signs, altered mental status, oliguria, direct or indirect evidence of bleeding and change in drainage from surgical sites should trigger focused evaluation relevant to patient complaints with imaging and collection of laboratory data. The older patient and individuals with significant comorbidities should receive particular attention as they are at risk for rapid decompensation.

Patients at greater risk for perioperative deterioration can be identified by measures intended to detect reduced physiologic reserve resulting in limited resistance to adverse postoperative events. A variety of interventions reduce perioperative risk such as optimization of nutrition, control of alcohol and tobacco use, appropriate preparation of organs to be treated in the operating room, conditioning as possible, use of minimally invasive surgical techniques which reduce operative trauma and avoidance of opioids where practical in postoperative pain management.

Identification of patients at risk and rapid intervention to support these individuals based on threatened organ systems is essential to restore a favorable hospital course in the postoperative patient.

II. RAPID RESPONSE

A variety of complications can occur after surgery. Postsurgical complications can be general (eg, hemorrhage) or more specific to the type of procedure performed (eg, anastomotic leak after small bowel resection). Complications can manifest immediately or several days after surgery. Close monitoring of patients who have undergone any surgical intervention, whether it be minor or major, is essential for the identification, management, and prevention of these complications. Specific surgical emergencies and management, including airway, neurologic, cardiovascular, abdominal, and musculoskeletal, will be discussed in depth in the following chapters.

Early recognition and intervention in a surgical emergency can improve a patient's outcome and prevent further complications. Patients who have surgery are at higher risk for rapid deterioration, and in certain circumstances, immediate surgical intervention is indicated for survival. If a patient has undergone surgery and is exhibiting abnormal signs and symptoms in the postoperative period, what is your approach?

A. Approach to the Surgical Patient

1. Diagnosis

Often you are called to the bedside for an acute change in a patient's clinical condition. **Table 3-1** provides examples of vital signs and clinical changes in a patient's condition that require immediate attention. These changes in a postoperative patient can potentially indicate a surgical emergency.

Table 3-1 Acute Changes in Patient's Condition

- Altered mental status
- Uncontrolled pain
- Heart rate >90 beats/min or <60 beats/min
- Systolic blood pressure <90 mm Hg
- Respiratory rate >20 breaths/min or <8 breaths/min
- Oxygen saturation <90%
- Decrease in urine output
- Bleeding from the surgical site
- Nausea and/or vomiting
- Change in color or volume of surgical drain/catheter output
- Signs of infection or other change in surgical incision site

A thorough and timely physical examination is essential to an accurate diagnosis. The patient's clinical status will often prioritize the examination. The emphasis is on a quick, focused examination centered on acute symptoms. Keeping in mind the patient's recent surgery, an overall assessment includes history, vital signs, visual and physical examination, and data collection (medications, laboratory and diagnostic tests).

2. Visual Examination

Subtle changes in vital signs (eg, mild tachycardia and increased respiratory rate) can occur as an inflammatory response to surgery. However, severe changes (hypotension and significant tachycardia) can suggest something more severe, such as shock.

Observe the patient's overall appearance and condition (eg, level of distress). Assess vital signs, which should include the following: heart rate, blood pressure reading (arterial blood pressure and waveform or noninvasive cuff), respiratory rate, and pulse oximetry reading. This is a quick assessment that should take no more than a few minutes. If the patient is unstable, focus on optimizing the patient's hemodynamics and follow the ABC mnemonic: airway, breathing, and circulation.

3. Physical Examination

Prioritize the examination based on the chief complaint and other associated symptoms. As you perform your physical examination, simultaneously assess whether the patient is alert and oriented. If the patient is lethargic or unresponsive, and there is no contraindication, with gentle pressure, rub the patient's sternum with a closed fist to assess whether he or she is awake and can move all extremities. Acutely ill patients may be agitated, obtunded, or delirious. Altered mental status is often secondary to a metabolic disturbance or medications administered in the postoperative period, such as analgesics. Neurosurgical patients should undergo a detailed neurologic examination quickly.

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Continue to assess the level of consciousness and distress throughout the examination.

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Assess whether there are signs of intracranial pathology such as a seizure, stroke, or herniation. Observe for seizure activity (abnormal movements or shaking), check pupil response, or any spontaneous eye movement. If the patient can cooperate with a neurologic examination, assess for signs of a stroke such as facial drooping, arm drift, and slurred speech. Reassess the patient's vital signs and ensure the patient is protecting his or her airway. The patient may require immediate intervention at this time (benzodiazepine for seizure or intubation for respiratory distress).

One of the most common problems after surgery is pain. A thorough assessment of pain is vital for reaching a differential diagnosis in surgical emergencies. If the patient cannot cooperate with your examination, look for signs of pain such as facial cues, agitation, or physiologic changes (elevated heart rate and blood pressure) throughout the examination. If the patient can participate in the review, a useful method to assess pain is the OLDCARTS mnemonic: Onset, Location, Duration, Characteristics, Alleviating/Aggravating factors, Radiation, Treatment, and Severity. Pain can be accompanied by other symptoms such as diaphoresis, nausea, or vomiting.

Respiratory distress after surgery can be a primary or a secondary variable. Apply supplemental oxygen as needed. Assess the patient's overall appearance, mental status, skin color (cyanosis), work of breathing, and use of accessory muscles. Tachypnea is often the first sign of serious illness. Auscultate breath sounds and assess whether the chest is symmetrically rising. Perhaps the recent surgical intervention put the patient at risk for pneumothorax or hemothorax. Be mindful of patients at high risk for pulmonary embolism and look for associated symptoms (rapid breathing, chest pain, and tachycardia). If the patient has a chest tube, assess for a leak, obstruction, and output color and volume.

A change in the patient's hemodynamics after surgery, such as hypotension and tachycardia, can be a sign of shock (hypovolemic, neurogenic, anaphylactic, cardiogenic, or septic). If time permits, review previous vital signs to detect changes or trends in the patient's condition. Note the mean arterial pressure (MAP) and check for signs of inadequate organ perfusion (eg, altered mental status, slow capillary refill, the skin is cool to touch). Postoperative patients are at risk for hypovolemic shock as a result of severe blood loss or under-resuscitation during or after surgery. The patient's recent surgery will give you clues for the type of shock. Look for signs of bleeding from the surgical site and drains. If a patient underwent abdominal surgery with large-volume resuscitation, or there is a concern for intra-abdominal bleeding, look for signs of elevated intra-abdominal pressure (IAP). High IAPs can cause intra-abdominal hypertension and lead to abdominal compartment syndrome, which is a surgical emergency. Elevated IAP decreases blood flow to abdominal organs and the inferior vena cava (IVC), causing increased intracranial pressure (altered mental status), decreased cardiac output (hypotension), and decreased urine output. The patient can also be in septic shock from an intra-abdominal source (anastomotic leak, perforation, or mesenteric ischemia) after abdominal surgery. The abdomen can mask infection; therefore, a thorough abdominal examination to rule out acute abdominal pathology should be performed with close attention to peritoneal signs (guarding, tenderness to percussion, rebound tenderness), surgical incisional site, and drains.

Observe for any arrhythmias associated with hypotension. Obtain an electrocardiogram (ECG) to analyze the rate and rhythm. Note any recent medications administered that can cause hypotension or an arrhythmia.

Patients who are elderly, have a history of diabetes mellitus, or have chronic corticosteroid use may not present with typical signs of acute abdominal pathology.

Inspect the surgical incision for dehiscence (opening of the surgical incision), evisceration (abdominal organs protrude from incision), signs of infection (erythema or purulent drainage), or bleeding. Make a note of any drains, the output color, and volume. Serosanguinous drainage is normal; purulent drainage is often a sign of infection, bilious or enteric drainage may indicate an anastomotic leak, and bright red drainage is concerning for acute hemorrhage. It is essential to know the surgical procedure performed and the specific location of surgical drains or catheters to anticipate potential complications. A review of the surgical notes and a discussion with the operating surgeon often reveals pertinent information that can help guide your diagnosis and management.

Assess the patient's skin for pallor or cyanosis, temperature, rash, or increased capillary refill. Remove opaque dressings to evaluate wounds or incisions carefully. If the patient had recent surgery or trauma to a limb, assess carefully for pulses or worsening edema.

B. Patient Management

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Delegate specific tasks to staff members to facilitate timely management.

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Surgical emergencies require early intervention given the patient's high risk of rapid deterioration. Once the likely diagnosis is reached, time is of the essence. Therefore, a prompt consult with the appropriate surgical team is prudent. The patient may have undergone spinal surgery, but if the diagnosis is a pneumothorax, the cardiothoracic surgical team should be informed.

The focus should always remain on the patient's clinical condition. The clinical presentation should prioritize your management decisions; for example, the patient may need to be intubated and mechanically ventilated before the surgical intervention. The presentation will also drive specific laboratory or diagnostic tests that may be useful for diagnosis and treatment. Such tests may include the following: an arterial blood gas (ABG), lactate, complete cell count with differential (CBC), fibrinogen, basic metabolic panel (BMP), creatine phosphokinase (CPK), amylase, lipase, liver function tests, PT/PTT, and cardiac enzymes. Also, ensure the patient has an active blood type and screen and activate the massive transfusion protocol if indicated. Obtain pertinent imaging that can be done quickly and efficiently at the bedside; for example, ultrasonography of the abdomen for abdominal pathology concerns, a portable chest radiograph to evaluate the lungs or rule out abdominal free air, or an abdominal radiograph to evaluate for free air, ileus, or obstruction. Further imaging (eg, CT scan) may help confirm a diagnosis, but given the patient's instability, it may be too risky for transportation at this critical time. Integrate all the objective and subjective information you have obtained to form a principal diagnosis.

The ultimate goal is to optimize and stabilize the patient. Continue to monitor the patient's mental status, vital signs, repeat the focused assessment, and frequently recheck your interventions. At this time, patients may need to be triaged to a higher level of care while waiting for surgical management. It is also essential to keep the patient and family apprised of the situation and plan.

C. Case Resolution

Consider the patient from the case study described previously.

- How does the patient appear?
- Is she in distress?
- What are her complaints?

She has increasing abdominal pain and bloating. Review her recent vital signs, which are as follows: temperature 38.6°C (101.4°F), blood pressure 99/59 mm Hg, heart rate 110 beats/min, respiratory rate 26 breaths/min, and pulse oximetry 93% on room air. On examination, the patient is confused, tachypneic, and the abdomen is tense, distended, and inappropriately tender to palpation with murky output from the Jackson-Pratt (JP) drain.

Keep in mind her recent surgery (left sigmoidectomy). Based on her signs and symptoms and physical examination (increased abdominal pain and murky output from the JP drain), she likely has an intra-abdominal process such as an anastomotic leak or abscess. At this time, obtaining a CBC, BMP, lactate, and upright chest or abdominal radiograph to assess for free air can help make a definitive diagnosis and guide management.

Inform the surgical team and discuss the patient's clinical presentation and intraoperative events. While awaiting laboratory and diagnostic tests, supportive treatment should be initiated (eg, oxygen therapy, fluid resuscitation, antibiotics). Continuous monitoring of patient presentation, the trend in vital signs, and response to interventions are imperative at this time.

III. FAILURE TO RESCUE

Complications and adverse events are known to occur with hospitalized surgical patients. Although the teams of providers caring for the patient work to avoid these, the providers need to have a high index of suspicion to care for the patient. It was once presumed that hospitals that have fewer complications have less mortality; therefore, they give better care. But there is a growing body of literature that reveals that this is not always true. Some hospitals have high reported complication rates but have lower mortality rates. When investigated why this is true, it was found that those hospitals that have higher mortality rates may not be as proficient at recognizing and managing complications as they occur, a phenomenon known as “failure to rescue.”

A. Complicating Factors

All hospitals experience perioperative emergencies. Effective rescue improves outcomes.

Failure to rescue refers to the inability to save someone’s life after the development of a complication. Overall, complication rates were found to be influenced more by patient factors (eg, age, comorbidities, etc.) than hospital factors, whereas hospital factors predominantly determined failure to rescue rates. The skills needed to intervene appropriately before the onset of life-threatening health problems require complex assessment, highly intensive therapies, targeted interventions, critical evaluation, and immediate adjustment dependent on patient response. Failure to rescue had the highest incidence of patient safety indicators and accounted for 62% of all the patient safety indicators among older patients.

Failure to rescue is a multifactorial issue. Often, clinicians become aware of problems when the patient is acutely decompensating and needs urgent, drastic measures. However, a review of the patient's chart often demonstrates the patient's instability was developing hours before the urgent need for assistance was recognized. To prevent failure to rescue, many institutions have attempted to develop tools to elucidate subtle changes in the patient's status. Examples are the use of early warning scoring systems or nursing dashboards. These methods give staff, providers, bedside nursing, and supervising staff quick clinical surveillance tools. The scores, if accurate, could be used to adjust the setting, staffing, and monitoring used to improve patient safety (**Table 3-2**).

Table 3-2 Surgical Acuity Staffing Grid (Sample)

Problem	RN: Patient Ratio
Dialysis/CRRT	2:1
Unstable, Ongoing Massive Transfusion	2:1
Neuromuscular Blockade	1:1
Prone Ventilation	1:1
Multiple Vasoactive Drugs	1:1
Pentobarbital for Elevated ICP	1:1
TPA Administration (first 8 hours)	1:1
Others	1:2

B. Medical Response Teams

Given the consequences of failure to rescue, institutions have tried to improve surveillance, recognition, and response-to-rescue events. One approach to this has been the development of Medical Response Teams (MRT). The MRT is activated for patients in which the healthcare team is experiencing a concern for their patients, or they meet predetermined criteria. Typically considered a crisis team, MRTs bring an additional experienced provider with an advanced skill set to the bedside. This allows for advanced techniques and procedures to be performed in an expedited fashion as well as ensure the patient is receiving the most appropriate care level. The Institute for Health Care Improvement has identified that the use of these teams is one of six changes needed to prevent death in patients that were deteriorating outside the intensive care unit (ICU).

MRTs typically are comprised of physicians, nursing, and ancillary staff, such as respiratory therapists, laboratory technicians, and pharmacists. Each institution must tailor their team to their available personnel. Typically, physicians have some training in critical care or emergency medicine. Nursing team members are usually composed of members that have many years of bedside critical care experience. Ancillary staff members allow for advanced procedures and testing to take place.

Many centers have different criteria on when a MRT should be activated. These are usually centered around physiologic criteria, organ-specific criteria, or event triggers such as a patient's failure to respond to a prescribed therapy. The criteria should be distributed to all staff and allow the staff to call for additional help and to call early.

IV. DAMAGE CONTROL AND COMPLICATIONS

A. Damage Control Surgery

> *Damage control is focused on addressing immediately life-threatening pathologies such as bleeding and source control.*

The concept of damage control as it relates to major surgical procedures and resuscitation in critically ill patients requiring emergent surgical intervention represents a giant leap forward; it provides a potential survival advantage to those patients who are too ill or physiologically deranged to undergo definitive surgical management at the time of the initial surgical intervention. By not attempting to force early definitive management, the patient may be more likely to survive and eventually recover.

The concept of damage control surgery was first publicized over 20 years ago. The idea parallels the concept of naval damage control in which in the face of devastating damage, essential maneuvers are rapidly deployed to prevent a damaged ship from sinking. In essence, similar concepts are performed during the initial operation of the critically ill patient. The basic idea involves control of significant bleeding and ongoing contamination and performing only essential surgical procedures needed for short-term survival. After the abbreviated initial surgical intervention, the patient is packed open, a temporary surgical closure is performed, and the patient is admitted to the ICU for further resuscitation, warming, correction of coagulopathy, and stabilization. After the patient has been stabilized and physiology has been normalized, the patient is then taken back to the operating room where definitive surgical procedures are performed, and the patient is (hopefully) closed traditionally. Although the concept was initially described for the trauma patient with massive bleeding, the paradigm has been extended to the field of emergency surgery with promising results.

B. Damage Control Resuscitation

Similar to damage control surgery, damage control resuscitation has been described. In response to severe injury and massive hemorrhage, the common practice had been the aggressive resuscitation with isotonic crystalloid with the goal of early normalization of blood pressure while preparing for definitive surgical control of bleeding; this concept was popularized in the 1970s. Based on military experience in the early 2000s, there was increasing recognition that this practice was associated with worsening coagulopathy and high mortality. Instead, an alternative resuscitation strategy was proposed. Rather than aggressive crystalloid resuscitation to normalize blood pressure, patients with massive hemorrhage are allowed to be relatively hypotensive, limiting resuscitation to keep a systolic blood pressure of approximately 90 mm Hg until definitive surgical control of bleeding is achieved. Further, when resuscitation is initiated, rather than isotonic crystalloid, a balanced mix of blood products including packed red blood cells, fresh frozen plasma, and platelets are used, approximating the components of fresh whole blood. Adherence to these resuscitation principles was associated with better outcomes, including decreased mortality, less lung injury, decreased ICU stays, and decreased ventilator days.

However, with the increased survival in these critically ill patients comes a whole host of new complications that must be identified and managed. While the operative issues require specialized surgical and anesthetic expertise, overall critical care medical and nursing needs can be defined for the non surgical team.

C. Complications of Damage Control

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Vasoactive drug use parallels practice for septic shock.

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Patients treated with a damage control strategy typically have serious physiologic derangements immediately following their initial damage control operation. These issues include life-threatening coagulopathy, hypothermia, septic shock, hypovolemia, acute kidney injury, and significant electrolyte and metabolic abnormalities. Ongoing fluid losses through the temporary abdominal closure should be recognized.

1. Coagulopathy

Prompt identification and vigorous correction of coagulopathy are critically important. Regardless of the method used to identify the coagulopathy, which might include traditional laboratory tests including PT/PTT/INR/Fibrinogen or the use of viscoelastic tests, such as thromboelastography (TEG) or rotational thromboelastometry (ROTEM), providers need to be prepared to administer blood products aggressively to correct any deficiencies. The role of off-label use of factor VIIa or prothrombin complex concentrates is controversial in these situations.

While any coagulopathy is being corrected, volume resuscitation must be continued to correct any ongoing hypovolemia aggressively. In the case of acute blood loss with ongoing coagulopathic hemorrhage, a balanced resuscitation with packed red blood cells, fresh frozen plasma, and platelets is preferred, especially if viscoelastic testing is not available to guide the resuscitation. In septic shock, isotonic crystalloid is likely the fluid of choice, with the possible addition of colloid if large volumes are needed. Care should be taken to avoid over-resuscitation because this may increase bowel and tissue edema making subsequent abdominal closure difficult, if not impossible. The use of dynamic monitoring to guide resuscitation is recommended. Using lactate as a marker for tissue hypoperfusion and guide for resuscitation in the postoperative patient may be helpful but does not singularly replace other markers.

2. Vasopressors

Vasopressor use, if required, should follow standard recommendations for the treatment of septic shock. However, caution needs to be taken in the face of any worsening hemodynamic instability or increasing vasopressor requirements to ensure that the patient has not developed hypovolemia. In the setting of coagulopathic hemorrhage after injury, volume resuscitation with blood and blood products should be the first line of resuscitation. Use of vasopressors should be reserved for specific situations, and even then, only after ensuring that the patient is not hypovolemic. However, even without any ongoing hemorrhage, intra-abdominal fluid losses may be markedly increased. They must be accounted for in the resuscitation, especially in the setting of severe peritonitis with a temporary abdominal closure device in place.

3. Electrolytes

Electrolyte abnormalities need to be identified and aggressively corrected. Calcium is of specific concern because it is crucial for muscle contraction and hemodynamics; it is an essential cofactor in the coagulation cascade. It is subject to depletion in the setting of massive transfusion because of citrate chelation. Other electrolyte deficiencies should be aggressively replaced. In the setting of acute kidney injury with severe acidosis or hyperkalemia, providers should consider early renal replacement therapy, typically with continuous renal replacement therapy or conventional hemodialysis and as hemodynamics dictate.

4. Nutrition

Once physiology has corrected, consideration should be made for early enteral nutrition after consultation with the surgical team. However, it is critical to note that in many cases where the bowel is resected at the time of a damage control procedure, the intestine is left in discontinuity with the ends stapled off. In such cases, enteral nutrition or even enteral medication administration is contraindicated, and the gastrointestinal (GI) tract should remain decompressed with a gastric tube in place to wall suction. However, if early enteric nutrition is possible, its use is associated with decreased bowel edema and greater success at early abdominal closure.

5. Nursing

In addition to the medical issues, important nursing considerations exist in the care of these patients. Critical care nurses must be familiar with the types of devices used for temporary abdominal closure at their institution. These can easily range from commercially available negative pressure wound therapy devices with closed systems, to closures requiring connection to wall suction, to improvised closure devices. Each will require slightly different management. In cases of device failure, evisceration can occur. If this happens, the exposed bowel should be covered with a moist, sterile dressing and emergent contact made with the surgical team to arrange for reoperation or device replacement at the bedside.

6. Analgesia and Sedation

One important consideration is ensuring the administration of adequate sedation and analgesia. This is important from a patient comfort standpoint, but also to ensure that patient movement and abdominal muscle contracture is limited because excessive movement might lead to increased risk of failure of the temporary closure device. These agents may trigger a hypotensive response.

7. Monitoring

Close patient monitoring is required. Monitoring both the volume of output and character of fluid from the closure device is also essential. Increasing or excessive fluid loss may lead to hypovolemia and indicate the need for additional volume replacement. A change in fluid character, either more bloody or bilious, may indicate recurrent intra-abdominal bleeding or the development of a bowel leak. Either may suggest the need for early reoperation by the surgical team.

Other important monitoring points include patient temperature and, in some cases, bladder pressure. Hypothermia is common in patients undergoing damage control procedures, especially in the setting of massive blood loss and transfusion. Active external rewarming is essential to correct hypothermia, especially in cases of ongoing coagulopathy. In cases of worsening physiology, hemodynamics, or renal function, consideration should be given to monitoring bladder pressures. It is possible to have an initial or recurrent abdominal or retroperitoneal compartment syndrome, even with an open abdomen.

D. Reoperation

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Radiographs help identify a residual foreign body in abdominal wall closure.

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After the correction of physiologic abnormalities, coagulopathy, sepsis, and hypothermia, the surgical team will consider the timing of reoperation. The exact timing will depend on many factors, including the need for additional surgical procedures such as additional bowel resections or anastomosis creation, the degree of bowel edema, the respiratory status, the overall volume status, and patient stability. Ideally, initial reoperation should occur within 1 to 3 days of the initial procedure. At the time of reoperation, care needs to be taken to ensure that any packing material left in the patient is removed, and hospital procedures often dictate that imaging studies be obtained at the time of closure for verification. Early abdominal closure should be the goal; delays place the patient at risk for multiple complications, including the development of enterocutaneous fistula or loss of abdominal domain where the fascia of the abdominal wall retracts. The presence of persistent bowel or tissue edema may complicate closure. In such cases, primary abdominal closure may become difficult, if not impossible. Surgical options include multiple reoperations or the possibility of a mesh closure with a planned ventral hernia and the need for subsequent abdominal wall reconstruction.

V. RISK MODIFICATION

A. Frailty

In the coming decade, up to 20% of the population in the United States is expected to be older than 65 years. Consistent with the aging population, emergency surgeons are experiencing an increase in the number of elderly patients. This is of particular concern because elderly patients have worse outcomes than younger patients with similar surgical insults or injuries. Although the increased vulnerability in the elderly may be a function of the effects of age and comorbidities, it is also postulated to be a result of frailty. Frailty is a syndrome encompassing multiple domains characterized by decreased physiologic reserve and reduced resistance to stressors. Unfortunately, there is a lack of consensus on the operational definition of frailty and how to assess or measure it. There are several frailty assessment tools for elderly patients undergoing elective surgery. There remains, however, a critical need for valid and clinically useful assessment for elderly trauma and emergency surgery patients whose injuries or other insults may preclude testing otherwise feasible in the elective surgical patient at a preoperative appointment, such as gait speed, mobility testing, or a comprehensive geriatric assessment (**Table 3-3**).

Recent data suggest that frailty is a more powerful predictor of increased perioperative mortality, morbidity, and cost than predictions based on age or comorbidity alone. For example, when compared with robust patients, frail surgical patients are less likely to be discharged to home, more likely to be readmitted to the hospital within 30 days, and more likely to have perioperative complications and mortality.

A significant challenge in the care of the surgical patient lies with the patient's journey through various parts of the process: outpatient clinics, preoperative units, operating room, postoperative recovery facilities, and the surgical ward. Each of the previously mentioned patient care units has separate personnel and capabilities. Each unit impacts the patient's care and communication between the care teams is vital. Consistent agreement on the end points of the patient's management is essential for coordinated care.

Table 3-3 Summary of Commonly Used Preoperative Frailty Scoring

Assessment	Domain(s) Measured	Frailty Scoring	Comments
Comprehensive, validated frailty scores			
Fried-Hopkins	Weakness (decreased grip strength); weight loss; exhaustion; low level of physical activity; slowness	Score of 4–5	Resources required; time required to complete
Rockwood-Robinson	Dependence in activities of daily living; decreased mobility; high comorbidity burden; abnormal cognition; poor nutrition; anemia; geriatric syndrome	4 or greater traits of frailty	Includes additional factors of dependence in daily activities and functional impairment; time required to complete
Surrogates of frailty measures			
Gait speed	Slowness; time to walk 15 ft (4.5 m)	6 seconds or greater to complete	Simple assessment
Handgrip strength	Weakness; decreased grip strength	<30 kg for men <20 kg for women	Adjusted for sex and body mass index
Time up and go	Mobility; rise from a chair, walk and return to chair	15 seconds or greater	Time required to complete

Data taken from Anaya DA, et al. Summary of the Panel Session at the 38th Annual Surgical Symposium of the Association of VA Surgeons. What Is the Big Deal About Frailty? *JAMA Surg*. 2014;149(11):1191-1197.

Table 3-4 summarizes steps which can be taken to improve chances of recovery after surgical procedures. No single element by itself will improve outcomes from surgery. The approach to perioperative care is multimodal, using all available aspects of care that improve recovery. It is essential to seek synergy between one process element and the next. Frequently components of recovery are guided by different medical and healthcare specialties working in various departments. Thus, a multidisciplinary approach is necessary. Many of the listed elements of care are carried out by allied health professionals alongside physicians and surgeons. Most important in this process is coordinated review and auditing of all components of the preoperative preparation and recovery teams to ensure coordinated and committed care with each subspecialist providing essential elements from their skill set.

Table 3-4 Steps to Enhanced Recovery after Surgery

1: Preadmission	2: Preoperative	3: Intraoperative	4: Postoperative
• Provide instruction for nutritional support • Encourage cessation of tobacco use • Recommend control of alcohol consumption • Optimize patient's medical status • Prepare and supply preoperative information	• Apply selective bowel preparation • Provide preoperative carbohydrate support • Prevent nausea and vomiting with prophylaxis	• Perform minimally invasive surgery • Minimize use of drains and tubes • Employ regional analgesia • Use opioid-sparing anesthesia • Administer balanced fluids • Maintain temperature control	• Remove drains early • Stop intravenous fluids • Provide opioid-sparing pain control • Mobilize patient early in recovery • Begin oral intake early

Data taken from *JAMA Surg* 2017; 152:292-298.

B. Frailty Screening

Frailty screening is an example of a quality improvement metric designed to address factors contributing to increased perioperative morbidity and mortality. Frailty screening begins with assessing the patient's cognition, strength, endurance, fatigue, comorbidities, and nutrition. This information is gathered by simple patient questionnaires and on preoperative examination. Interventions aimed at mitigating elements of frailty may be helpful before surgery. Often, however, the patient's frailty cannot be reversed. For these patients, perioperative preparation should include formal discussions with surgeons, anesthesiologists, and intensivists to alert the patient and health care team to risks associated with proposed surgery and a prognosis for 6-month mortality. When appropriate, formal preoperative palliative care consultation focusing on clarifying goals and expectations for surgery and recovery, including discussions of ventilator dependence, dialysis, and do not resuscitate status, should be conducted.

!

Frail patients are often identified with questionnaires or demographic data.

With the implementation of frailty screening, 30-day mortality decreased by over 50% in a population of elective general surgery patients. Improvement in outcome was highest among patients identified as frail, and 30-day mortality fell from 12.2% down to 3.8%. Remarkably, mortality rates also decreased among patients not seen as frail. The magnitude of improvement among frail patients increased in the 12 months after screening.

C. Sarcopenia and Osteopenia

Because of the limitations of functional testing or completion of medical questionnaire data in the acute setting, a variety of investigators have sought surrogate markers with prognostic value such as sarcopenia, defined by low muscle mass and impaired muscle function. Sarcopenia is a predictor of ventilator-free days, ICU-free days, discharge disposition, and mortality among older high-acuity patients. Like sarcopenia, osteopenia is also related to the pathophysiology of frailty and is associated with poor outcomes. Frailty is associated with multiple falls and fractures. Low bone density increases the risk of hip, spine, and extremity fractures. It is possible to repurpose cross-sectional imaging obtained for various reasons to screen for sarcopenia or osteoporosis. Thus, opportunistic use of imaging, specifically CT, may be applied in the acute surgery setting in which a large population of patients undergo CT imaging as part of routine evaluation. Given that radiologic evidence of sarcopenia or osteopenia is associated with underlying physical frailty through shared pathologic pathways, opportunistic screening for sarcopenia and osteopenia may fill a significant gap in frailty assessment.

Evaluation of osteopenia and sarcopenia in emergency surgery patients admitted to the ICU who survived to discharge revealed that radiologic indicators of frailty were strongly predictive of 1-year mortality even after adjustment for age and other comorbidities. Physical frailty, sarcopenia, and osteopenia are intertwined on a pathophysiologic level. Traditional frailty assessment instruments only include criteria for sarcopenia and osteopenia through shared characteristics such as weakness, weight loss, or falls. It remains unclear whether radiologic indicators stand alone as a substitute for traditional frailty evaluation instruments. Current evidence suggests that the formal addition of sarcopenia improves the prognostic accuracy of traditional frailty evaluation instruments.

Key Points

Approach to the Surgical Patient, Part 2: Surgical Emergencies

- Changes in end-organ function and key vital signs provide a useful warning of acute changes in the condition of the surgical patient.
- Patient history, review of the surgical notes, and discussion with the operative surgeon will help guide the diagnosis and management of acute signs and symptoms.
- The ability to identify and stabilize patients after perioperative complications determine effectiveness in healthcare teams.
- The damage control approach identifies and addresses immediate life-threatening problems. Typical emphasis is on spillage of bowel contents and bleeding.
- Patients requiring damage control interventions are at risk for coagulopathy and frequently will require serial surgical procedures.
- Patient characteristics indicative of increased surgical risk can be identified during preoperative screening, and patients counseled, surgical risk modified, and surgical outcomes improved.

Suggested Readings

1. Beckman M, Paul J, Neideen T, Weigelt JA. Role of the open abdomen in critically ill patients. *Crit Care Clin*. 2016;32:255-

264.

2. Cheatham ML, Malbrain ML, Kirkpatrick A, et al. Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome. II. Recommendations. *Intensive Care Med*. 2007;33(6): 951-962.

3. Chovanes J, Cannon JW, Nunez TC. The Evolution of Damage Control Surgery. *Surg Clin North Am*. 2012;92(4):859-875. doi:10.1016/j.suc.2012.04.002.

4. Dracup K, Bryan-Brown CW. From novice to expert to mentor: Shaping the future. *Am J Crit Care*. 2004;13(6):448-450.

5. Fitzpatrick ER. Open abdomen in trauma and critical care. *Crit Care Nurse*. 2017;37(5):22-45.

6. Ghaferi AA, Birkmeyer JD, Dimick JB. Complications, failure to rescue, and mortality with major inpatient surgery in Medicare patients. *Ann Surg*. 2009;250(6):1029-1034.

7. Hall DE, Arya S, Schmid KK, et al. Association of a frailty screening initiative with postoperative survival at 30, 180, and 365 days. *JAMA Surg*. 2017;152(3):233-240.

8. Holcomb JB, Jenkins D, Rhee P, Johannigman J. Damage control resuscitation: Directly addressing the early coagulopathy of trauma. *J Trauma*. 2007;62(2):307-310.

9. Illuzzi E, Gillepsie M. Physical examination in the ICU. In: Critical Care. Oropello JM, Vladimir K, Pastores SM (eds). Lange, McGraw-Hill, New York, 2017; pp101-110.

10. Kaplan SJ, Pham TN, Arbabi S, et al. Association of radiologic indicators of frailty with 1-year mortality in older trauma patients. Opportunistic screening for sarcopenia and osteopenia. *JAMA Surg*. 2017;152(2):e164604.

11. Ljungqvist O, Scott M, Fearon KC. Enhanced recovery after surgery: A review. *JAMA Surg*. 2017; 152:292-298.
12. McDonald VS, Thompson KA, Lewis PR, et al. Frailty in trauma: A systematic review of the surgical literature for clinical assessment tools. *J Trauma Acute Care Surg*. 2016;80(5):824-834.
13. Oropello JM, Vladimir K, Pastores SM. Critical Care: Lange. McGraw-Hill, New York. 2017.
14. Rotondo MF, Schwab CW, McGonigal MD, et al. “Damage control”: An approach for improved survival in exsanguinating penetrating abdominal injury. *J Trauma*. 1993;35(3):375-382.
15. Silber JH, Williams SV, Krakauer H, Schwartz JS. Hospital and patient characteristics associated with death after surgery: A study of adverse occurrence and failure to rescue. *Med Care*. 1992;30(7):615-629.
16. Thompson JS, Baxter BT, Allison JG, et al. Temporal patterns of postoperative complications. Arch Surg. 2003;138(6):596-603.
17. Wakeam E, Hyder JA. Raising the Bar for Failure to Rescue: Critical Appraisal of Current Measurement and Strategies to Catalyze Improvement. *JAMA Surg*. 2015;150(11):1023-1024.

Suggested Websites

1. Trauma.org
   http://www.trauma.org/archive/resus/DCSoverview.html
2. https://derangedphysiology.com/main/required-reading/trauma-burns-and-drowning/Chapter%203.0.4/damage-control-surgery
3. https://lifeinthefastlane.com/ccc/damage-control-resuscitation/
4. https://lifeinthefastlane.com/ccc/thromboelastogram-teg/

5. http://www.practical-haemostasis.com/Miscellaneous/Miscellaneous%20Tests/teg.html
6. https://derangedphysiology.com/main/required-reading/haematology-and-oncology/Chapter%201.2.0/viscoelastic-tests-clotting-function-teg-and-rotem
7. ERAS Society Enhanced recovery after surgery. http://www.erassociety.org.

Chapter 4

DIAGNOSIS AND MANAGEMENT OF ACUTE RESPIRATORY FAILURE

Objectives

- Define and classify acute respiratory failure.
- Describe the pathophysiology and manifestations of acute respiratory failure.
- Review the management of acute respiratory failure.

Case Study

A 58-year-old-man presents to the emergency department in the winter with a few days of worsening dyspnea, productive cough, fever, and malaise. He is an active smoker with known chronic lung disease, obesity, hypertension, hyperlipidemia, and diabetes mellitus. He does not see the doctor much, and reports inconsistent adherence with his medications. The patient is awake but slightly lethargic. He appears to be in moderate respiratory distress with evident use of accessory muscles during inspiration and expiration and a respiratory rate of 30 breaths/min. Audible crackles are present in the right posterior lung fields with scattered expiratory wheezes. You are called to assess the patient and initiate treatment.

– How would you prioritize the immediate needs for this patient?

– What tests would be useful to stratify the severity of this patient's condition?

– Which respiratory support should be considered?

– What pharmacologic treatment(s) should be initiated?

I. INTRODUCTION

Acute respiratory failure (ARF) is one of the leading causes of admission to the ICU. It is defined as a lack of capacity of the respiratory system and/or other vital organs, such as the brain and heart, to meet the patient's oxygenation, ventilation, or metabolic requirements. The pulmonary system is involved in two crucial functions: elimination of carbon dioxide (CO_2) and oxygenation of the blood. There are three types of respiratory failure: hypoxemic, hypercapnic, and mixed. Hypoxemic respiratory failure, historically known as type 1, is defined by a room air PaO_2 of $\leq$ 60 mm Hg ($\leq$ 6.7–8 k Pa) or an abnormal ratio of PaO_2 to fraction of inspired oxygen (PaO_2:FIO_2, or P:F ratio; discussed later). This abnormality of PaO_2 should exist in the absence of intracardiac right- to-left shunting. Hypercapnic respiratory failure, or type 2, is defined by a $PaCO_2 \geq 50$ mm Hg ($\geq$ 6.7 k Pa) that is not caused by respiratory compensation for metabolic alkalosis, usually with a pH < 7.35. Mixed respiratory failure has features of both hypercapnia and hypoxemia and is a common form of respiratory failure in critically ill patients. Respiratory failure is considered chronic once the renal system attempts compensation with the retention of bicarbonate. This usually occurs over days of persistent hypercapnia and the resulting respiratory acidosis. Frequently, in patients with chronic lung disease, ARF may be superimposed on chronic respiratory insufficiency. In such circumstances, the acute component is distinguishable from the chronic component by the degree of respiratory acidosis (as defined by an abnormal pH) in relation to $PaCO_2$ and elevated bicarbonate values and knowledge of baseline oxygen requirements.

II. CAUSES OF ACUTE RESPIRATORY FAILURE

Acute respiratory failure develops in a variety of clinical settings. It may result from primary pulmonary insults or from other systemic non-pulmonary disorders, as summarized in **Table 4-1**. Diseases of the central nervous system, neuromuscular system, upper and lower airways, pulmonary parenchyma, pulmonary vasculature, thoracoabdominal cavity, and cardiovascular system may all give rise to ARF.

Hypoxemic respiratory failure may be seen in disorders that interfere with the oxygenation of the blood as it circulates through the alveolar capillaries. This may occur in patients with severe pneumonia, acute respiratory distress syndrome

(ARDS), or acute pulmonary edema. Hypercapnia most often results from inadequate alveolar ventilation, which results in ineffective CO_2 clearance. This can be seen in patients with severe airflow obstruction, central respiratory failure, or neuromuscular respiratory failure.

Table 4-1 Causes of Respiratory Failure

	Hypoxemic		
Airways	**Lung Parenchyma**	**Vascular**	**Trauma**
Bronchospasm Tracheobronchial injury Obstruction Inhalational lung injury	Infection/pneumonia ARDS Interstitial lung disease Atelectasis Neoplasm Chronic bronchitis/emphysema Cystic fibrosis/bronchiectasis Pulmonary edema	Pulmonary embolism Pulmonary hypertension Congenital heart disease Congestive heart failure Fat embolism	Pneumothorax Hemothorax Blast lung injury Pulmonary laceration Toxic inhalation (smoke, chlorine gas)
	Hypercapnic		
Drugs	**Metabolic**	**Intracranial**	**Trauma**
Opioids Benzodiazepines Other sedatives NMB agents	Hypocalcemia Hypothyroidism/myxedema Hypophosphatemia	Encephalitis/meningitis Stroke/CVA Increased intracranial pressure (central hypoventilation)	Rib fractures/flail chest Burn eschar Spinal cord injury Diaphragmatic injury
Chest Bellows	**Lung Parenchyma**	**Neuromuscular/Musculoskeletal**	**Upper Airway**
Obesity hypoventilation syndrome Abdominal compartment syndrome	End-stage COPD/cystic fibrosis	Kyphosis/scoliosis Myasthenia gravis Multiple sclerosis Guillain-Barré syndrome Amyotrophic lateral sclerosis Poliomyelitis Botulism	Tonsillar/adenoid enlargement Goiter Epiglottis Vocal cord paralysis Laryngeal edema Tracheomalacia Obstructive sleep apnea

Abbreviations: ARDS, acute respiratory distress syndrome; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; NMB, neuromuscular blockade.
Reproduced with permission Pamplin J, Borgman M, eds. *Fundamental Critical Care Support: Resource Limited*. Mount Prospect, IL: Society of Critical Care Medicine; 2020.

The following are common ICU scenarios that lead to ARF:

- Chronic obstructive pulmonary disease (COPD) exacerbations are characterized by increased thick mucopurulent secretions as well as wheezing secondary to bronchospasm. They are often associated with both hypoxemic and hypercapnic acute respiratory failure (ie, mixed ARF).

- Pneumonia is most commonly associated with hypoxemic respiratory failure, although it also can be associated with hypercapnic respiratory failure, especially in the setting of other chronic lung diseases such as COPD.
- ARDS is a manifestation of a severe systemic inflammatory response caused by pulmonary or non-pulmonary injury or disease. Hypoxemic respiratory failure predominantly occurs because of an increased shunt fraction from alveolar filling.
- Traumatic brain injury is associated mainly with hypercapnic respiratory failure, although it can be complicated by hypoxemic respiratory failure in the setting of concurrent aspiration, pulmonary contusions, neurogenic pulmonary edema, or chronic pulmonary disease.
- Medication or substance overdose usually occurs from central nervous system-depressing agents, such as benzodiazepines, opioids, or barbiturates. It presents with hypercapnic respiratory failure secondary to a centrally mediated decreased respiratory drive resulting in alveolar hypoventilation.
- Decompensated congestive heart failure is associated with predominantly hypoxemic failure secondary to alveolar filling and increased shunt; however, hypercapnic respiratory failure may also occur in severe exacerbations or in the presence of pulmonary disease.

III. PATHOPHYSIOLOGY OF ACUTE RESPIRATORY FAILURE

A. Hypoxemia

Hypoxemia signifies a decrease in the partial pressure of oxygen (PaO_2) in the blood. Hypoxia defines a state in which the supply of oxygen to the body as a whole or a specific region is inadequate. Although the usual definitions of hypoxemic respiratory failure include pulse oximetry (SpO_2) and PaO_2, additional measurements of oxygenation, mechanisms of hypoxemia, and the degree of its impact include: the alveolar-arterial (A-a) gradient, the ratio of PaO_2 to the fraction of inspired oxygen (FIO_2) known as the P:F ratio, and the oxygenation index (OI).

Regardless of how hypoxemic respiratory failure is defined or monitored, the important clinical context is how the degree of hypoxemia results in tissue hypoxia.

Alveolar-arterial gradient:

The A-a gradient is the oxygen gradient between the alveolar oxygen partial pressure (PAO_2) and the content of dissolved oxygen in the arterial supply (PaO_2). A normal A-a gradient for a young healthy adult is usually 5–10 mm Hg, but increases with age. An age-adjusted approximation for the A-a gradient = (Age/4) + 4. The calculation for A-a gradient is:

$$\text{A-a gradient} = PAO_2 - PaO_2$$

PaO_2 is measured by obtaining an ABG analysis, whereas PAO_2 is calculated by the following equation:

$$PAO_2 = FIO_2 \times (PATM - PH_2O) - (PaCO_2/R)$$

FIO_2 is the fraction of inspired oxygen (0.21 at room air)

PATM is the atmospheric pressure (760 mm Hg at sea level)

PH_2O is the partial pressure of water (47 mm Hg at 37°C)

$PaCO_2$ is the partial pressure of CO_2 obtained from the ABG analysis

R is the respiratory quotient (approximately 0.8)

P:F Ratio:

The PaO_2:FIO_2 (P:F) ratio, in which PaO_2 is measured as mm Hg and FIO_2 is the fraction of inspired oxygen, is a measurement of oxygenation that accounts for the amount of supplemental oxygen that the patient is requiring. It is a simple calculation that is most commonly used in patients with hypoxemic respiratory failure, specifically ARDS, to classify the severity of their disease process and trend it over time. A normal P:F ratio is usually 300–500. Based on the Berlin definition of ARDS, the P:F ratio stratifies the severity of the hypoxemia and provides indications for certain advanced management therapies. The most accepted definition of ARDS is the Berlin definition, which was updated in 2012. To be classified as having ARDS, a patient must meet all three of the following criteria:

!

The P:F ratio can be helpful for following trends in a patient's condition and evaluating ventilation strategies.

!

- Onset within 7 days after a known clinical insult or new or worsening symptoms
- Bilateral diffuse alveolar opacities on chest imaging (chest radiograph or CT scan)
- P:F ratio < 300*

Mild : 201 to 300

Moderate: 101 to 200

Severe: < 100

*P:F ratio is measured at a minimum PEEP setting for CPAP of 5 cm H_2O.

Oxygenation Index (OI):

The OI is a measurement of oxygenation dysfunction that takes into account mean airway pressure while a patient is on mechanical ventilation.

$$OI = [100 \times (\text{mean airway pressure (cm } H_2O) \times FIO_2]/PaO_2$$

An OI of ≥ 25 can indicate severe hypoxemia. The OI has some advantages over the P:F ratio. The two main techniques to improve alveolar oxygenation for a patient on positive pressure ventilation are to increase the FIO_2 and the airway pressure (the latter commonly by increasing positive end-expiratory pressure [PEEP]). Thus, two different patients with the same PaO_2 and FIO_2 can have different mean airway pressures but the same P:F ratios; therefore, their different OIs will more accurately predict the discrepancy in oxygenation dysfunction.

For Example:

Which patient has a higher likelihood of worse outcomes?

Patient 1: PaO_2 65 mm Hg, FIO_2 80%, PEEP 10, PIP 30, MAP 20*, P:F 0.8 = OI 21

Patient 2: PaO_2 65 mm Hg, FIO_2 80%, PEEP 18, PIP 40, MAP 29*, P:F 0.8 = OI 26

Answer: Patient 2 with an OI of > 25 has more severe hypoxemia with evidence of worse lung compliance, and ultimately a higher mortality rate compared with Patient 1.

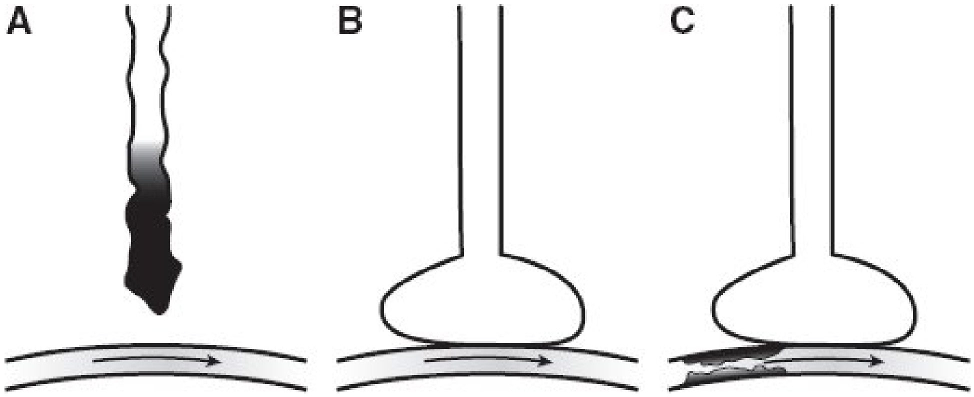
Abbreviations: PIP, peak inspiratory pressure; Ti, inspiratory time.
*Mean airway pressure (MAP) based on Ti 1.0, respiratory rate 30 breaths/min, pressure based on presumed lung compliance differences.

Mechanisms of Hypoxemia:

The four main mechanisms of hypoxemia are ventilation/perfusion $(\dot{V}/\dot{Q})$ mismatch, hypoventilation, diffusion impairment, and reduced inspired oxygen tension (PIO_2).

The most common underlying physiologic abnormality in hypoxemic respiratory failure is a mismatch of alveolar ventilation $(\dot{V})$ and pulmonary perfusion $(\dot{Q})$, as illustrated in **Figure 4-1**. The mismatch of ventilation and perfusion, where ventilation is decreased relative to perfusion, is called low $\dot{V}/\dot{Q}$. $\dot{V}/\dot{Q}$ matching is particularly important to oxygenation of blood as opposed to elimination of CO_2 (discussed in Section IV) because of the kinetics of the hemoglobin oxygen dissociation curve. Although there is normally a heterogeneous amount of ventilation and perfusion among the upper, middle, and lower lung zones, significant decreases in either $\dot{V}$ or $\dot{Q}$ contribute to a $\dot{V}/\dot{Q}$ mismatch with a net result of hypoxemia. Lung areas with high $\dot{V}/\dot{Q}$ ratios, which provide a high PaO_2, cannot compensate for areas with a low $\dot{V}/\dot{Q}$ ratio (providing low PaO_2) as the hemoglobin molecule is already about 90% saturated at a PaO_2 of about 60 mm Hg. The admixture of poorly oxygenated blood returning from abnormal alveoli dilutes oxygenated blood from more normal lung units, resulting in systemic hypoxemia. The hypoxemia caused by $\dot{V}/\dot{Q}$ mismatch is usually easily corrected by supplemental oxygen.

Figure 4-1. Ventilation and Perfusion Matching in the Lung



A, At the end of the pathologic continuum, areas of limited ventilation relative to perfusion produce shunt effect and hypoxemia. **B**, Ventilation and perfusion are matched in the normal lung. **C**, At the opposite of the continuum, areas of better ventilation than perfusion produce dead space effect.

Diseases that cause progressive obstruction of distal airways, alveolar filling, or atelectasis (eg, pneumonia, aspiration, pulmonary edema) result in decreased oxygen availability in the distal airways for uptake through the pulmonary capillaries. Subsequent hypoxic pulmonary vasoconstriction results in decreased blood flow to these abnormal lung units. Although this decline has a lower effect than the decrease in oxygen availability, it results in a greater proportion of deoxygenated blood (venous admixture) that is returned to the left side of the heart.

One extreme of $\dot{V}/\dot{Q}$ mismatch is shunt because there is perfusion of the unventilated lung. In diseases that cause diffuse alveolar flooding (eg, ARDS), refractory hypoxemia may be the result of shunt physiology. Treatment of hypoxemia caused by $\dot{V}/\dot{Q}$ mismatch should be directed toward treating the underlying cause such as infections, reversing airway obstruction, reopening (recruiting) atelectatic lung zones, and preventing closure (de-recruitment) of the affected lung units. Oxygen therapy and/or mechanical ventilation are cornerstones in providing support until such time that the cause of $\dot{V}/\dot{Q}$ mismatch has been reversed.

Other causes of hypoxemia include:

- Decreased diffusion of oxygen across the alveolocapillary membrane complex because of interstitial edema, inflammation, fibrosis, etc.
- Alveolar hypoventilation
- High altitude with low inspired partial pressure of oxygen

Diffusion abnormality is rarely the primary cause for hypoxemia because oxygen transport across the alveolocapillary membrane is generally perfusion limited rather than diffusion limited; however, in cases such as increased cardiac output and tachycardia, diffusion may be limited when the transit time across pulmonary capillaries is reduced. Therapy for diffusion abnormalities, in addition to maintaining adequate circulating volume, includes treatment of the cause of interstitial pathology (ie, diuretics for cardiogenic pulmonary edema, corticosteroids for inflammatory disorders). Ensuring adequate minute ventilation will correct hypoxemia that is solely the result of hypoventilation. High altitude is a rare cause of acute hypoxemia in patients. As a compensatory treatment strategy, providing oxygen supplementation (FIO_2) while the cause of the hypoxemia is investigated and corrected may improve oxygenation.

B. Hypercapnia

Hypercapnic respiratory failure is caused by either excess CO_2 production or decreased effective alveolar ventilation. Alveolar minute ventilation (VA) is determined by the tidal volume (VT), the respiratory rate frequency (f), and physiologic and anatomic dead space (VD).

$$VA = (VT - VD)f$$

Hypercapnia has a multitude of causes as listed in **Table 4-1**. In general, healthy individuals do not display symptoms of hypercapnia until the $PaCO_2$ rises about 70 to 80 mm Hg, whereas patients with chronic hypercapnia may be able to tolerate $PaCO_2$ levels as high as 90 to 120 mm Hg before becoming symptomatic. Hypercapnic respiratory failure, therefore, has a different $PaCO_2$ threshold for each patient but can be summarized as the condition in which insufficient CO_2 removal by the lungs necessitates medical therapy and/or ventilatory support.

Hypercapnia, resulting from either decreased VT or the respiratory rate frequency, may occur with drug ingestions or anesthetics that lead to depression of the medullary respiratory centers. An elevated $PaCO_2$ normally increases the ventilatory drive. Therefore, hypercapnic respiratory failure implies that the patient is unable to sustain minute ventilation (f × VT).

Treatment of decreased VT or respiratory rate may require reversal of sedation or other drugs, endotracheal intubation with mechanical ventilation to rest fatigued muscles, supplemental nutrition, respiratory stimulants, or treatment of other possible primary causes. For neuromuscular disorders such as myasthenia gravis and Guillain-Barre syndrome, serial measurement of ventilatory mechanics, such as negative inspiratory force and forced vital capacity, can dictate when mechanical ventilation is warranted. Either a negative inspiratory force below -20 to 25 cm H_2O or forced vital capacity < 10 mL/kg, should raise concern that a patient's ventilatory mechanics are sufficiently impaired and mechanical ventilation is needed. Desaturation or hypoxemia cannot be relied on because they are secondary to alveolar hypoventilation, and therefore a late finding of respiratory failure.

> *The more rapidly the negative inspiratory pressure and forced vital capacity deteriorate, the lower the threshold for intubation and mechanical ventilation.*

Increased physiologic dead space (VD) may also produce hypercapnia and is another type of mismatch illustrated in **Figure 4-1**. When gas flow to and from airways remains adequate but blood flow is diminished, CO_2 does not have the opportunity to diffuse out of the pulmonary circulation, and CO_2-rich blood is returned to the left atrium. Increased dead space ventilation may occur in respiratory muscle fatigue from any cause, leading to rapid shallow breathing. Increased VD may also be seen in hypovolemia, pulmonary embolism, poor cardiac output, or when the regional airway pressure is relatively higher than the regional perfusion pressure, reducing pulmonary blood flow in that area.

Strategies to reduce dead space may include reduction in peak or mean airway pressures, if the patient is receiving mechanical ventilation, augmentation of intravascular volume and/or cardiac output, or treatment of other causes for limited pulmonary blood flow. It may be possible to compensate for hypercapnia caused by high VD by modifying parameters to increase minute ventilation during mechanical ventilation while the cause of hypercapnia is sought and corrected. Because of the high solubility of CO_2, a diffusion barrier rarely ever occurs. Increased CO_2 production may contribute to hypercapnia secondary to either excess carbohydrate nutritional calories or extreme hypercatabolic conditions (eg, burns, hyperthyroidism, persistent fever).

C. Mixed Respiratory Failure

Patients commonly demonstrate characteristics of both pathophysiologic categories of ARF during the course of illness. An understanding of each underlying pathophysiology is necessary to plan the appropriate therapeutic support. Several related disease processes often act synergistically to compound respiratory failure. For example, the patient with chronic pulmonary disease and a large dead space often has associated heart failure, which increases $\dot{V}/\dot{Q}$ mismatching and worsens hypoxemia. In a patient with severe ARDS, pulmonary interstitial and alveolar edema result in increased intra-pulmonary shunt and dead space, and decreased functional lung size because of alveolar collapse; subsequently, the shunt contributes primarily to hypoxemia while increased deadspace causes hypercapnia, resulting in mixed respiratory failure.

IV. MANIFESTATIONS OF ACUTE RESPIRATORY FAILURE

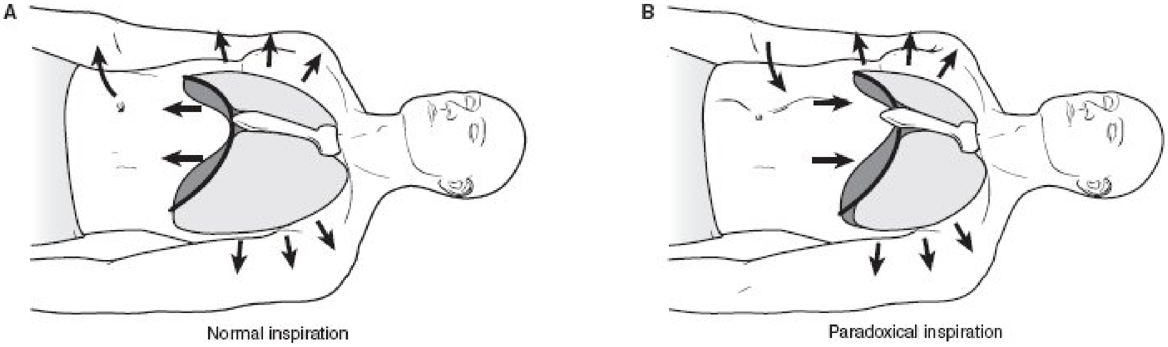
A. Clinical Presentation of Respiratory Distress

Clinical manifestations of respiratory distress commonly include signs and symptoms of hypoxemia, hypercapnia, or both. These include:

- Altered mental status ranging from agitation to somnolence
- Evidence of increased work of breathing, such as nasal flaring in infants, use of accessory respiratory muscles, intercostal/suprasternal/supraclavicular muscle retraction, tachypnea, hyperpnea, or a paradoxical or dysynchronous breathing pattern (**Figure 4-2**)
- Bradypnea

- Cyanosis of mucosal membranes (eg, tongue, mouth) or nail beds
- Diaphoresis, tachycardia, hypertension, and other signs of catecholamine release

Figure 4-2. Normal Versus Abnormal Respiration



Normal inspiration

Paradoxical inspiration

A, The abdominal wall moves outward as the diaphragm moves downward in normal inspiration. **B**, With respiratory muscle fatigue, the diaphragm becomes flaccid and moves upward during inspiration resulting in inward movement of the abdominal wall.

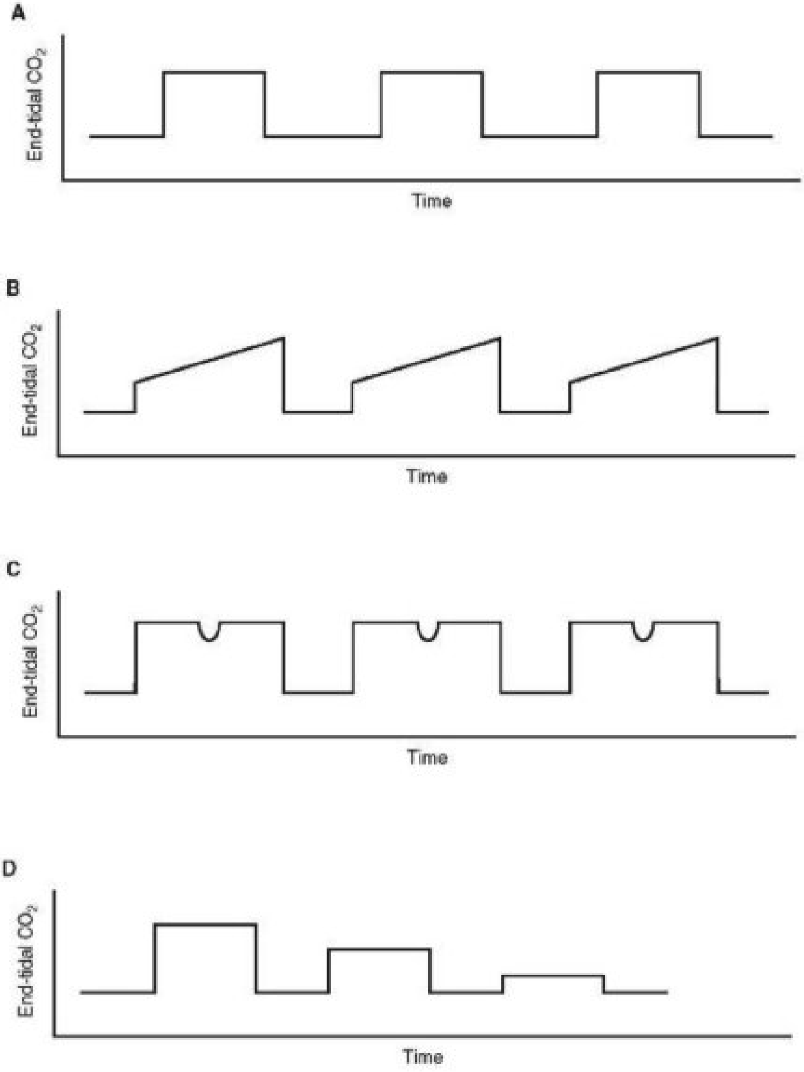
B. Diagnostic Tests

> *Waveform capnography (end-tidal CO_2 [$ETco_2$]) may be used as a surrogate for $PaCO_2$*

Pulse oximetry can be used to rapidly evaluate oxygenation in a patient with respiratory distress by estimating the arterial oxyhemoglobin saturation. However, pulse oximetry provides no assessment for hypercapnia. Arterial blood gas analysis is commonly used in severely ill patients to determine the two primary measures of respiratory failure, the PaO_2 and $PaCO_2$, as well as pH. Additional tests, such as electrolytes, hematocrit, and drug levels, may provide clues to the underlying etiology of ARF. Chest radiography and bedside ultrasonography in combination with these laboratory tests is invaluable in suggesting the underlying pathophysiology of ARF.

Waveform capnography (end-tidal CO_2 [$ETCO_2$]) is a measure of the partial pressure of exhaled CO_2 and may be used as a surrogate for $PaCO_2$ (**Figure 4-3**). Although $ETCO_2$ may not accurately reflect actual $PaCO_2$ because of alterations in dead space ventilation (areas of the lung in which ventilation occurs but there is no perfusion), $ETCO_2$ trends are useful for monitoring patient ventilation, especially when ABG analysis is limited or unavailable. In addition, capnography provides reassurance that an endotracheal tube (ETT) or tracheostomy is in place, particularly during transport.

Figure 4-3. Waveform Capnography



A, Normal. **B**, Status asthmaticus. **C**, Trigger dyssynchrony. **D**, Worsening hypoventilation.

V. MANAGEMENT CONSIDERATIONS

A. Oxygen Supplementation

Most patients with ARF require supplemental oxygen. Oxygen transfer from alveolar gas to capillary blood occurs by diffusion across the alveolar-capillary membrane and is driven by the oxygen partial-pressure gradient between the partial pressure of alveolar oxygen (PaO_2) and the PO_2 of the pulmonary capillary blood. In most cases of ARF, the PaO_2 can be substantially increased by use of supplemental oxygen, thus increasing the gradient across the membrane and improving the PaO_2.

Supplemental oxygen can be provided by a variety of devices (**Figure 4-4**). The effectiveness of each is determined by its capacity to deliver sufficient oxygen at a high enough flow rate to match the patient's spontaneous inspiratory flow rate. Matching between the flow capacity of the oxygen device and the patient's inspiratory flow demand determines how much room air is entrained by the nonintubated patient breathing in an open system. Any entrained room air (FIO_2 = 0.21) will dilute (decrease) the FIO_2 of the delivered gas in such a way that the tracheal FIO_2, and hence PaO_2, may be considerably lower than the FIO_2 delivered from the oxygen source. Therefore, oxygen-supplement systems are usually classified as high oxygen (capable of delivering up to 100% oxygen), controlled oxygen (set oxygen percentage), or low oxygen. Similarly, the devices are also categorized as either high flow, moderate flow, or low flow, reflecting the flow-delivery capacity of the gas at the preset FIO_2 level. **Table 4-2** provides an overview and compares some commonly used supplemental oxygen delivery devices.

Table 4-2 Comparison of Supplemental Oxygen Delivery Devices

Device	O_2 Flow (L/min)	FIO_2 (%)	Benefits	Limitations and Complications
Low-flow nasal cannula	1–6	24–45	Low cost, compact, portable	Upper respiratory tract drying/ bleeding when not humidified
Simple face mask	1–15	25–90	Simple device with higher FIO_2 than nasal cannula	Upper respiratory tract drying/ bleeding when not humidified
Nonrebreather mask	10–15	60–90	Simple device with high FIO_2	When using high flow rate, can consume O_2 supply quickly
High-flow nasal cannula (heated & humidified)	10–60	21–100	Delivers high-flow, heated, humidified air, matches patient with high minute ventilation	Expensive, not very portable, requires power

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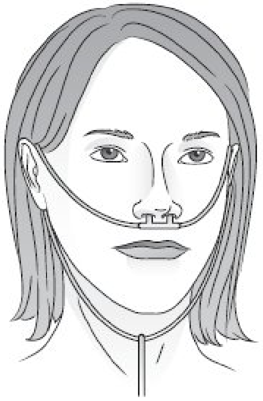
> *Supplemental oxygen should be considered a temporizing intervention while the primary etiology of hypoxemia is diagnosed and treated.*

For example, a tachypneic and hyperpneic patient will have a high inspiratory flow rate during each breath. In such cases, hypoxemia is less likely to respond well to oxygen supplementation by nasal cannula because it is a low-oxygen, low-flow system and cannot match the patient's high inspiratory flow rate. Room air will be entrained during inspiration, and the tracheal FIO_2 will be reduced. A high-oxygen, high-flow system should be selected for this type of patient.

Figure 4-4. Oxygen Delivery Devices

A. Nasal Cannula

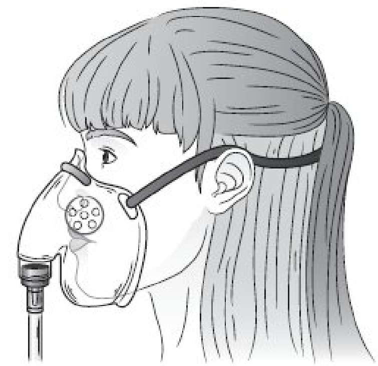


- Delivers humidified oxygen
- Nasal passages must be patent
- Blender setup: F_{IO_2} is set by dial; 1-2 L flow can be used as continuous positive airway pressure for infants
- Wall setup: F_{IO_2} is set by flow rate
- Approximate F_{IO_2} (if respiratory rate and tidal volume are normal):

Adult

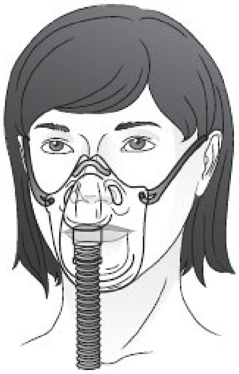
1 L = 24%	4 L = 36%
2 L = 28%	5 L = 40%
3 L = 32%	

B. Simple Oxygen Mask



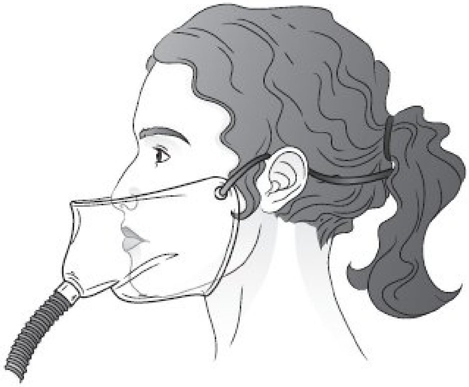
- Delivers humidified oxygen
- Minimum flow rate = 6 L/min (to clear exhaled CO_2 from mask)
- Approximate concentrations: 6 L = 40%; 7 L = 50%; 8L = 60%

C. Aerosol Mask



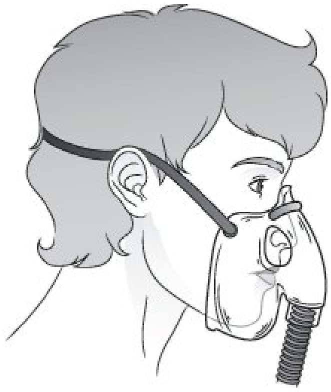
- Delivers cool, aerosolized oxygen or air
- F_{IO_2} = 40%-60%
- Minimum flow rate = 8 L/min

D. Face Tent



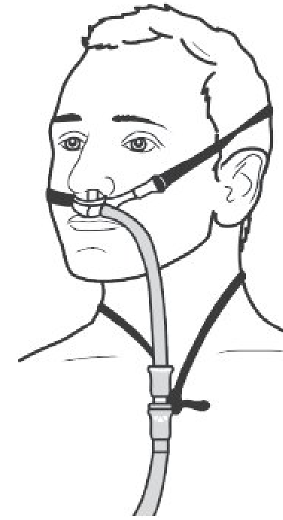
- Delivers cool, aerosolized oxygen or air
- Loose fit under the chin for patient comfort, speaking, etc.
- F_{IO_2} is set by dial on oxygen adapter (concentration is unstable)
- Maximum F_{IO_2} = 40%-50%
- Minimum flow rate = 8 L/min

E. Venturi Mask



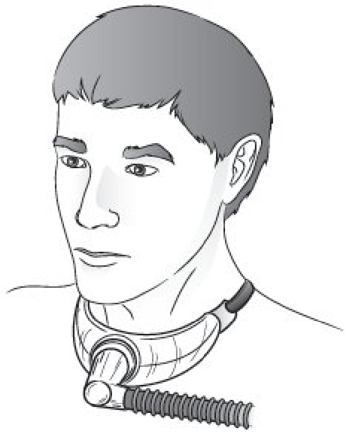
- Delivers humidified oxygen (aerosol adapter can be added)
- FIO$_2$ is set by entrainment dial on mask
- Low concentrations = 24%, 26%, 28%, 31%
- High concentrations = 35%, 40%, 50%

F. High-flow Nasal Cannula



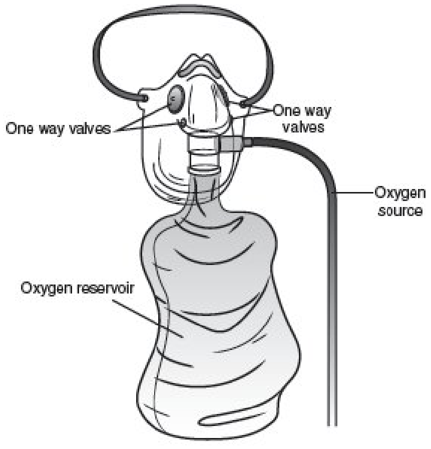
- Uses up to 100% oxygen source
- Flow rate <60 L/min

G. Tracheostomy Mask



- Delivers heated, aerosolized oxygen or air
- FIO$_2$ is set by dial on blender
- Maximum FIO$_2$ = 40%-60%
- Minimum flow rate = 8 L/min

H. Non-rebreather Mask



- Delivers non-humidified oxygen
- Used for emergency delivery
- FIO$_2$ range = 60 - 100%
- Reservoir bag provides 100% FIO$_2$ and minimized room air dilution
- Flap valves minimize entrainment of room air (which will dilute FIO$_2$)
- Flow rate is adjusted according to the patient's ventilator pattern to keep reservoir bag inflated to a maximum of 15 L/Min

1. Low-Flow Nasal Cannula

Short prongs of the nasal cannula are inserted into the nares. Oxygen (100%) is delivered through the cannula, but at a rate between 0.5 and 5 L/min. The resulting FIO_2 depends on the patient's minute ventilation and, therefore, cannot be precisely controlled, but the maximal tracheal FIO_2 is not likely to exceed 0.4 to 0.5 (40% to 50%). Higher flow rates do not result in much higher FIO_2 levels and have a drying and irritating effect on nasal mucosa. The nasal cannula is comfortable and well tolerated by many patients with ARF in whom precise control of FIO_2 is not necessary. It is a low-flow, low-oxygen device.

2. Aerosol Face Mask

The commonly used aerosol face mask combines a variable oxygen setting and moderate flows. The mask, which has large side holes, is attached by large-bore tubing to a nebulizer that blends 100% oxygen and room air to deliver gas at a preset FIO_2 level. Flow matching can be evaluated by observing the patient during spontaneous breathing. If the entire aerosol mist disappears from the mask during inhalation, the patient's inspiratory flow demands are probably exceeding the capacity of the nebulizer and room air is being entrained. The aerosol face mask is a variable oxygen, moderate-flow device.

3. Air-Entrainment Face Mask

Air-entrainment masks (also called Venturi masks) deliver oxygen through a jet-mixing device that increases the velocity of oxygen and causes a controlled entrainment. The FIO_2 can be more precisely controlled from 0.24 to 0.5 (24% to 50%) at high-flow rates simply by selecting the interchangeable jet nozzle and adjusting the oxygen flow rate. It is a high-flow, controlled-oxygen device.

4. Reservoir Face Mask

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A reservoir mask is frequently used for improving oxygenation in patients with severe hypoxemia until further evaluation and treatments are accomplished.

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The reservoir face mask incorporates a reservoir bag from which the patient breathes. This bag is filled with 100% oxygen from a supply source. The flow rate is adjusted so that the bag remains completely or partially distended throughout the respiratory cycle. When the mask is properly applied, oxygen delivery to the nonintubated patient can be maximized but rarely exceeds an FIO_2 of 0.6 to 0.9. The reservoir face mask is a high-oxygen, high-flow device.

5. Resuscitation Bag-Mask Unit

Although not commonly considered an oxygen-supplement device, bag-mask units are usually included with other emergency equipment and, therefore, are readily accessible. When the mask is held firmly over the patient's face, room air entrainment is largely excluded. If the oxygen flow to the bag is kept high ($\geq$ 15 L/min), a high-oxygen supply is provided at sufficient flow. The resuscitation bag need not be compressed to supply oxygen. It is a high-oxygen, high-flow device.

B. Advanced Oxygen Supplementation

1. High-Flow Nasal Cannula

High-flow nasal cannula (HFNC) systems involve delivery of heated and humidified oxygen at high flow rates. Standard oxygen therapy delivers dry and cold air into the respiratory tract, which may promote inflammation, increase airway resistance, and affect mucocilliary clearance. Conversely, heated and humidified air delivered via the HFNC has been shown to reduce airway resistance and airway inflammation while promoting secretion clearance.

HFNC may also improve respiratory mechanics because of the higher flow rates that it is capable of delivering. For example, in the setting of ARF, a patient's minute ventilation can far exceed 20 L/min. Whereas the nonrebreather mask can only achieve a flow of 15 L/min, the HFNC is capable of matching the patient's needs by reaching oxygen delivery at a flow of up to 60 L/min in adults. Furthermore, these high flow rates can generate a modest PEEP in the airway. Although debated, in general, up to 1 cm H20 of PEEP is generated for every 10 L/min of flow the system delivers, which improves oxygenation. Lastly, the high inspiratory flow rates wash out the CO2-rich exhalation air in the upper airway. As the pharyngeal dead space is reduced, the actual oxygen concentration reaching the alveoli is higher than with conventional oxygen therapy.

When setting the initial parameters for HFNC, flow rate should be titrated first (typically by 10 L/min increments) followed by FIO_2. Temperature may be set from 31°C (87.8°F) to 37°C (98.6°F) as tolerated by patient. If adequate saturation and/or improvement in work of breathing is not achieved when reaching 60 L/min with FIO_2 50%, endotracheal intubation should be considered.

Potential contraindications to HFNC include concomitant COPD because evidence has demonstrated that noninvasive positive pressure ventilation (NIPPV) has mortality benefit. If a patient requires endotracheal intubation, although has a do-not-intubate status, HFNC may be appropriate from both a therapeutic and a palliative perspective. The last indication, backed by consistent evidence, is the use of HFNC as a preoxygenation tool when performing rapid sequence intubation. HFNC has consistently shown to increase safe apnea time.

2. Noninvasive Positive Pressure Ventilation

NIPPV is a form of mechanical ventilation that provides respiratory assistance through a mask or helmet without a secure or invasive airway. Both oxygenation and ventilation can be augmented in the already breathing patient through the delivery of positive pressure and FIO_2, ranging from ambient air at 21% up to 100%. Some advantages and disadvantages of NIPPV are listed in **Table 4-3**.

Table 4-3 Advantages and Disadvantages of NIPPV

Advantages	Disadvantages
• Reduced need for sedation	• Claustrophobia
• Preservation of airway-protective reflexes	• Noise
• Avoidance of upper airway trauma	• Increased workload for respiratory practitioner
• Decreased incidence of nosocomial sinusitis and pneumonia	• Facial/nasal pressure lesions with prolonged use
• Improved patient comfort	• Unprotected airway
• Shorter ICU and hospital lengths of stay	• Inability to suction deep airway
• Improved survival	• Gastric distension
• Potential to reduce postextubation failure	• Delay in intubation

NIPPV encompasses several different modalities. The two modes most frequently used in patients with ARF are bilevel positive airway pressure (BiPAP) and continuous positive airway pressure (CPAP). Each mode has unique indications but share the same contraindications (**Table 4-4**). Overall, NIPPV can decrease mortality, endotracheal intubations, and ICU length of stay in a variety of clinical scenarios. However, it has been shown to increase mortality if used incorrectly. All types of NIPPV are contraindicated in patients who are not able to follow commands, cannot handle oral secretions appropriately, underwent recent esophageal surgery, have facial deformities, require restraints, and/or are hemodynamically unstable. As with HFNC, if work of breathing and/or oxygenation do not improve after an initial trial of NIPPV, endotracheal intubation should not be further delayed.

Table 4-4 Contraindications to NIPPV

- Cardiac or respiratory arrest
- Severe metabolic or respiratory acidosis (pH < 7.10–7.20)
- Hemodynamic instability
- Patient not protecting airway
- Poor respiratory drive/apnea
- Active emesis, upper gastrointestinal bleed, or excessive pulmonary secretions
- Trauma or burns involving the face
- Recent maxillofacial or transsphenoidal surgery
- Recent facial, esophageal, or gastric surgery
- Prolonged duration of NIPPV anticipated
- Severe agitation or anxiety requiring restraints
- Reduced level of consciousness or inability to follow commands
- Infectious respiratory outbreak (aerosolization of droplets from open respiratory circuit)

BiPAP may be indicated in several clinical scenarios. NIPPV has potential benefit for several patient types but is not ideal for all. Traditionally, patients with exacerbations of congestive heart failure or COPD can respond well with NIPPV as a bridge while the underlying process is addressed. Other situations in which NIPPV may provide benefit over mechanical ventilation or avoid the need for mechanical ventilation include immunocompromised patients with respiratory failure, patients with asthma exacerbation, postextubation, respiratory failure in patients with cystic fibrosis, intubation refusal, and palliative care. The use of NIPPV in ARDS is controversial. In some studies, it has been shown to decrease the rate of endotracheal intubation but does not influence overall mortality.

The initial setup for NIPPV and close monitoring of the patient within the first 1 to 2 hours are the most crucial aspects for ensuring success of NIPPV. Suggestions for initiation and monitoring NIPPV are highlighted in **Table 4-5**. The patient should be properly monitored in an environment in which a nurse, respiratory therapist, or physician has continuous direct observation of the patient and proper monitoring with heart rate, blood pressure, pulse oximetry, and ideally $ETCO_2$. Pre-NIPPV baselines for pH, $PaCO_2$ (or SpO_2), PCO_2 (or $ETCO_2$), respiratory rate, and patient comfort must be established, and clear ideal trajectory identified in these numbers and observations to indicate success or failure. Reassessment after initiating NIPPV should occur within 30 to 60 minutes. In general, if there is no improvement within 4 to 6 hours (or if there is earlier clinical decline), invasive mechanical ventilation should be strongly considered. Sedation should be used cautiously during NIPPV to avoid respiratory depression. Consider gastric decompression with a nasogastric tube if a helmet is used or the patient requires very high delivered pressures (above 15 cm H_2O). The patient's oral intake should be limited in the initial period in the event that gastric insufflation causes emesis or the patient fails NIPPV and requires invasive mechanical ventilation.

Table 4-5 Initiation, Early Titration, and Assessment of NIPPV

- Ensure that NIPPV is indicated (and there are no contraindications).
- Explain this ventilation mode to the patient, including expectations and goals.
- Establish baseline vital signs, blood gas results, and $ETco_2$.
- Identify clear criteria to determine success or failure.
- Properly fit mask or helmet.
- Initial Mode Options:

CPAP	**BiPAP**
PEEP 5–10 cm H_2O	EPAP 5 cm H_2O
Fio_2 100%	IPAP 10–15 cm H_2O
	Fio_2 100%
	Backup rate ≥ 6–8 breaths/min

- Adjust difference between IPAP and EPAP to achieve desired V_T (and V_A), measuring end effect with either $Paco_2$ or $ETco_2$.
- Titrate down Fio_2 as desired for Pao_2 or Spo_2.
- Reassess within 30 to 60 minutes and closely monitor thereafter until success or failure is clear.

Abbreviations: BiPAP, bilevel positive airway pressure; CPAP, continuous positive airway pressure; EPAP, expiratory positive airway pressure; $ETCO_2$, end-tidal carbon dioxide; FIO_2, fraction of inspired oxygen; IPAP, inspiratory positive airway pressure; NIPPV, noninvasive positive pressure ventilation; PaO_2, partial arterial oxygen pressure; $PaCO_2$, partial arterial carbon dioxide pressure; PEEP, positive end-expiratory pressure; SpO_2, oxygen saturation; VA, alveolar minute ventilation; VT, tidal volume.

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The initial parameters that are set include the inspiratory positive airway pressure (IPAP), expiratory airway pressure (EPAP), FIO_2, and back-up respiratory rate. The IPAP may be adjusted to manipulate ventilation parameters, while the EPAP (in conjunction with the FIO_2) may be adjusted to control oxygenation. A difference of at least 4 cm of water (cm H_2O) between the IPAP and EPAP is recommended. Parameters are titrated to promote a patient ventilation of 5–8mL/kg, improve oxygenation to 88–92%, while being comfortably tolerated. Initial reasonable BiPAP settings would be an IPAP of 8 cm H_2O, EPAP of 4 cm H_2O, FIO_2 of 50%, and a back-up respiratory rate of 12. If additional minute ventilation is required, increase IPAP accordingly; conversely, EPAP and FIO_2 may be titrated to improve oxygenation.

Patients with COPD who have been endotracheally intubated can be extubated earlier to BiPAP ventilation. This not only decreases days on mechanical ventilation, but also ICU length of stay and even mortality. CPAP is primarily indicated in hypoxemic respiratory failure secondary to acutely decompensated congestive heart failure (CHF). CPAP may be beneficial by several mechanisms. First, it maintains an elevated PEEP, therefore increasing mean airway pressure and, as a consequence, oxygenation. Secondly, in patients with CHF, as positive pressure is delivered, intrathoracic pressure increases. As a result, preload decreases, thereby reducing lung edema while decreasing afterload and promoting an increase in cardiac output. CPAP is the equivalent of EPAP in BiPAP. As discussed earlier, a starting point of 5 cm H_2O of CPAP may be adequate if the patient's saturation and work of breathing improve, although more typically a pressure of 8–10 cm H_2O may be required.

C. Pharmacologic Adjuncts

Many diseases that cause ARF produce similar anatomic and physiologic derangements, including bronchial inflammation, mucosal edema, smooth muscle contraction, and increased mucus production and viscosity. Each of these processes may contribute to obstruction of airway gas flow, increased airway resistance, mismatch, and elevated VD. Some pharmacologic agents may be helpful in the care of such patients and may directly alter shunt or dead-space effects.

1. β_2-Agonists

Inhaled β_2-agonists are important therapy in patients with ARF secondary to many causes. Stimulation of β_2-adrenergic receptors causes bronchial and vascular smooth-muscle relaxation. These agents are typically administered by metered-dose inhaler or by intermittent or continuous nebulization (**Table 4-2**). On rare occasions, in very critically ill patients with obstructive airway disease, β_2-agonists are administered by both inhalation and subcutaneous injection. Long-acting inhaled agents do not have a role in the management of patients with acute respiratory failure. Racemic epinephrine aerosol is an established therapy for upper airway obstruction in children with croup and is also used for laryngeal edema in adults.

2. Anticholinergic Agents

Ipratropium bromide competes with acetylcholine at the bronchial receptor site, resulting in bronchial smooth-muscle relaxation. This agent is delivered by metered-dose inhaler or nebulization (**Table 4-6**). Ipratropium has a more delayed onset of action than β_2-agonists and has more consistent bronchodilatory effects in COPD than in asthma. The addition of ipratropium to albuterol appears to have an additive benefit in approximately 30% of patients with asthma. Tiotropium is a long-acting anticholinergic bronchodilator that has sustained effects in patients with COPD; however, its use in acute exacerbations is not recommended.

Table 4-6 Pharmacologic Agents for Obstructive Airway Disease

Drug	Preparation	Route of Administration	Dosage
Albuterol	0.05 solution	Inhaled (aerosol)	*Adult:* 2.5-5 mg every 2-4 h[a] *Pediatric:* 0.05-0.15 mg/kg every 4-6 h[a]
	MDI (90 µg/puff)	Inhaled	*Adult:* 1-2 puffs every 2-4 h[a] *Pediatric:* 1-2 puffs every 4-6 h[a]
Levalbuterol	0.31, 0.63, or 1.23 mg/unit dose solution	Inhaled (aerosol)	*Adult and children ≥12 y:* 0.63-1.25 mg every 6-8 h *Pediatric (6-11y):* 0.31-0.63 mg every 6-8 h; more aggressive dosing may be used in acute exacerbations
	MDI (45 µg/puff)	Inhaled	*Adult:* 1-2 puffs every 4-6 h *Pediatric (age ≥4 y):* 1-2 puffs every 4-6 h
Metaproterenol Sulfate	5% solution	Inhaled (aerosol)	*Adult:* 0.3 mL every 2-4 h[a] *Pediatric:* 0.25-0.5 mg/kg every 2-4 h[a]
	MDI (0.65 µg/puff)	Inhaled	*Adult:* 2-3 puffs every 4-6 h[a] *Pediatric:* 1-3 puffs every 4-6 h[a]
Terbutaline	MDI (0.2 µg/puff)	Inhaled	*Adult:* 1-2 puffs every 4-6 h[a] *Pediatric:* 1-2 puffs every 4-6 h[a]
	0.1% solution	Subcutaneous	*Adult:* 0.2-0.4 mL; repeat in 15-30 min *Pediatric:* 0.2 mg/kg; maximum 6 mg
Epinephrine	1 mg/mL (1:1000)	Subcutaneous	*Adult:* 0.1-0.5 mg; repeat in 20-30 min *Pediatric:* 0.01 mg/kg
Inhaled Epinephrine	1 mg/mL (1:1000)	Inhaled	*Adult:* 2.5-5 mL every 3 h *Pediatric:* >4 y: 2.5-5 mL every 3 h; <4 y: 2.5 mL every 3 h
Ipratropium	0.025% solution	Inhaled (aerosol)	*Adult:* 500 µg every 6-8 h *Pediatric: Infant and child:* 250 µg every 6-8 h; >12 y: 250-500 µg every 6-8 h
	MDI (18 µg/puff)	Inhaled	*Adult:* 2-4 puffs every 6 h *Pediatric:* 1-2 puffs every 8 h

Abbreviations: q, every; MDI, metered-dose inhaler; NS, normal saline

[a] In patients with severe asthma, frequency of administration of inhaled β-agonists should be guided by response to therapy and risk for adverse effects. Therapy is routinely initiated with three treatments every 20 minutes. Further therapy adjustments are then based on response. Continuous nebulization may also be employed. Caution should be exercised when considering use of continuous nebulized β_2-agonists, particularly in older patients and those with underlying cardiac disease.

3. Corticosteroids

Providing corticosteroid therapy has a clear benefit for critically ill patients with respiratory failure who are at risk of an exacerbation of asthma or COPD. Although the central role of inflammation in obstructive airway disease is well established, corticosteroids may also decrease β-receptor tachyphylaxis. Intravenous and oral routes are equal in efficacy. Limited consensus exists on dosing schedules in asthma. Doses of methylprednisolone of 80 mg/24 h have been as effective as > 360 mg/24 h. Some clinicians use doses equivalent to those given for asthma when treating COPD, whereas others begin with doses equivalent to 1 mg/kg/24 h, adjusting as patient response dictates. Careful monitoring of corticosteroid adverse effects is warranted. Acute myopathies have been described after the administration of moderate to high dosages of corticosteroids in patients with COPD and/or asthma. After the acute exacerbation, inhaled corticosteroids are often useful adjuncts to therapy and may allow a reduction in systemic corticosteroid dosage. However, routine use of inhalational agents is not recommended in the setting of acute severe bronchospasm. In ARDS, the use of corticosteroids is not well understood, but may have some benefit in the late phase, between 7 and 13 days after onset.

4. Antibiotics

Bacterial infection (bronchitis/pneumonia) frequently precipitates ARF. Antibiotics should be used when there is clinical suspicion that a bacterial respiratory infection is present (eg, change in sputum characteristics, pulmonary infiltrates on the chest radiograph, fever, leukocytosis), and they should be chosen to effectively treat the usual pathogens. Therapy should be subsequently adjusted when culture and sensitivity data become available.

Several randomized trials have compared clinical outcomes in patients hospitalized with acute exacerbation of COPD and have shown antibiotic treatment has been associated with a decreased risk of adverse outcomes. When the decision is made to use antibiotics, it is important to distinguish a simple from a complicated case of acute exacerbation of COPD and a 5-day course is usually recommended.

D. Miscellaneous Agent and Treatments

Agents to hydrate or otherwise alter the composition, elasticity, or viscosity of mucus have been used, although their efficacy has not been consistently demonstrated except in selected patient groups (eg, patients with cystic fibrosis). Examples of these agents include mucolytics such as acetylcysteine or propylene glycol, bronchorrheic agents such as saturated solution of potassium iodide or glyceryl guaiacolate, and alkalinizing agents such as aerosolized sodium bicarbonate.

Postural drainage, chest physical therapy, nasotracheal suctioning, incentive spirometry, intermittent positive pressure breathing, and cough/deep-breathing exercises have long been used. Also available are newer measures such as positive expiratory pressure therapy, vest devices (high-frequency chest oscillator), and mattress percussion devices. Many of these modalities may be applied to treat specific symptoms of ARF or the cause of respiratory failure. The effectiveness and positive impact of the contributions of the bedside nurse or the respiratory care practitioner and the avoidance of intubation/mechanical ventilation should not be underestimated.

Key Points

Diagnosis and Management of Acute Respiratory Failure

- Acute respiratory failure is classified as hypoxemic, hypercapnic, or mixed. Arterial blood gas measurements are the primary assessment tool for determining this classification.
- The most common pathophysiologic mechanism for hypoxemic acute respiratory failure is ventilation/perfusion mismatch.
- Acute hypercapnic respiratory failure is primarily the result of a change in one or more determinants of the alveolar minute ventilation equation: tidal volume, respiratory frequency, and physiologic dead space.
- Oxygen supplementation is commonly used to treat hypoxemia. The oxygen supply device that is chosen must be capable of matching the oxygen and respiratory flow demands of the patient.
- Pharmacologic and therapeutic adjuncts should be considered when treating patients with acute respiratory failure.

Suggested Readings

1. Cannon J, Colombo C, Pamplin J, et al. Joint Trauma System Clinical Practice Guideline. Acute Respiratory Failure. U.S. Army Institute of Surgical Research. Publication date January 23, 2017. https://jts.amedd.army.mil/assets/docs/cpgs/JTS_Clinical_Practice_Guidelines_(CPGs)/Acute_Respiratory_Failure_23_Jan_2017_ID06.pdf. Accessed January 30, 2019.

2. Chiumello D, Brochard L, Marini J, et al. Respiratory support in patients with acute respiratory distress syndrome: an expert opinion. *Crit Care*. 2017;21(240):1-8.
3. Dolovich MB, Ahrens RC, Hess DR, et al. Device selection and outcomes of aerosol therapy: Evidence-based guidelines: American College of Chest Physicians/American College of Asthma, Allergy and Immunology. *Chest*. 2005;127(1):335-371.
4. Lodeserto FJ, Lettich TM, Rezaie SR. High-flow Nasal Cannula: Mechanisms of Action and Adult and Pediatric Indications. *Cureus*. 2018;10(11):e3639. Published 2018 Nov 26. doi:10.7759/cureus.3639
5. Manser R, Reid D, Abramson M. Corticosteroids for acute severe asthma in hospitalized patients. *Cochrane Database Syst Rev*. 2001;(1):CD001740. doi:10.1002/14651858.CD001740.
6. Marino PL. *The ICU Book*. 4th ed. Philadelphia, PA: Wolters Kluwer Health; 2014:391-464 and 487-586.
7. Pontoppidan H, Geffin B, Lowenstein E. Acute respiratory failure in the adult: 1. *N Engl J Med*. 1972;287:690-698.
8. Pontoppidan H, Geffin B, Lowenstein E. Acute respiratory failure in the adult: 2. *N Engl J Med*. 1972;287:743-752.
9. Pontoppidan H, Geffin B, Lowenstein E. Acute respiratory failure in the adult: 3. *N Engl J Med*. 1972;287:799-806.
10. Rochwerg B, Brochard L, Elliott MW, et al. Official ERS/ATS clinical practice guidelines: noninvasive ventilation for acute respiratory failure. *Eur Respir J*. 2017;50:1602426 [https://doi.org/10.1183/13993003.02426-2016].
11. Spinelli E, Mauri T, Beitler J, Pesenti A, Brodie D. Respiratory drive in the acute respiratory distress syndrome: pathophysiology, monitoring, and therapeutic interventions. *Intensive Care Medicine*. 2020;46(4):606-618.
12. Sponsler K, Markly D, Labrin J. What is the appropriate use of antibiotics in AECOPD. *The Hospitalist*. 2012 Jan 26. http://the-

hospitalist.org/issue/january-2012.

Chapter 5

SURGICAL AIRWAY EMERGENCIES

✓ Objectives

- Recognize emergency tracheostomy complications and take immediate action to re-establish the airway and adequate ventilation.
- Consider the clinical setting of postoperative neck hematoma and take immediate actions to control the airway and provide conditions for surgical reintervention.
- Learn symptoms of upper airway obstruction caused by angioedema.
- Review techniques for needle and surgical cricothyroidotomy.

Case Study

A 65-year-old man with a medical history of myocardial infarction and chronic obstructive pulmonary disease underwent a left carotid endarterectomy under regional anesthesia. On arrival to the intensive care unit (ICU), he had an infusion of sodium nitroprusside, with a mean arterial pressure of 110 mm Hg. He was conscious, with no neurologic deficit, and eupneic, with supplemental O_2 by nasal cannula and SpO_2 of 98%.

Two hours after arrival, the patient had a sudden drop of mean arterial pressure, below 50 mm Hg. He was unresponsive with a respiratory rate of 32 breaths/min, with an SpO_2 of 80%. Inspiratory and expiratory stridor was noted. While assisting respirations with a bag-valve-mask, the surgical dressing was noted to be displaced by a large firm mass under the suture line.

– What is the cause of the sudden worsening of this patient’s status?

- What are the risk factors for this complication?
- What should be your immediate interventions?

I. INTRODUCTION

It is reported that up to 20% of all critical incidents in the ICU are related to the airway and such incidents may occur at intubation, extubation, or during treatment.

This chapter focuses on airway issues specific to surgical patients.

Tracheostomy complications can challenge providers and acutely endanger patients. Providers should recognize which surgical procedures can put patients at the risk of surgical airway emergencies as the result of a postoperative neck hematoma. Also, it is important for providers to recognize upper airway obstruction resulting from angioedema (AE). An inadequate consciousness level may compromise the airway immediately after transfer from the postanesthetic care unit. Finally, this chapter reviews the indications, anatomy, and emergency surgical airway (needle/surgical cricothyroidotomy).

II. TRACHEOSTOMY EMERGENCIES AND EARLY COMPLICATIONS

Several complications and emergencies are related to a tracheostomy procedure. However, the three most common tracheostomy emergencies are:

1. Loss of airway: tube dislodgement, false lumen
2. Tube obstruction: mucus plugging, other tube malfunction
3. Bleeding: tracheoinnominate artery fistula, stoma hemorrhage

Early recognition of each of these conditions is the key to managing the airway successfully and adequately ventilating and oxygenating the patient until definitive surgical treatment is employed to restore the airway.

!

If a patient with a tracheostomy has trouble breathing, check whether the tube is in the correct position.

One of the early and potentially life-threatening tracheostomy complications and emergencies is tube displacement within the early post-procedure period (<7 days), before the stoma has matured and the tracheostomy tract has healed. The normal anatomy after tracheostomy is shown in **Figure 5-1**. The structure of the tracheostomy tube is shown in **Figure 5-2**. The loss of airway could be the result of the complete displacement of the tracheostomy tube (decannulation) or partial displacement (dislodgement) or when the tip of the tube is displaced into a false passage anterior to the trachea into the subcutaneous tissue. When dislodgement happens, quick diagnosis and immediate response are crucial to success.

Figure 5-1. Normal Anatomy after Tracheostomy

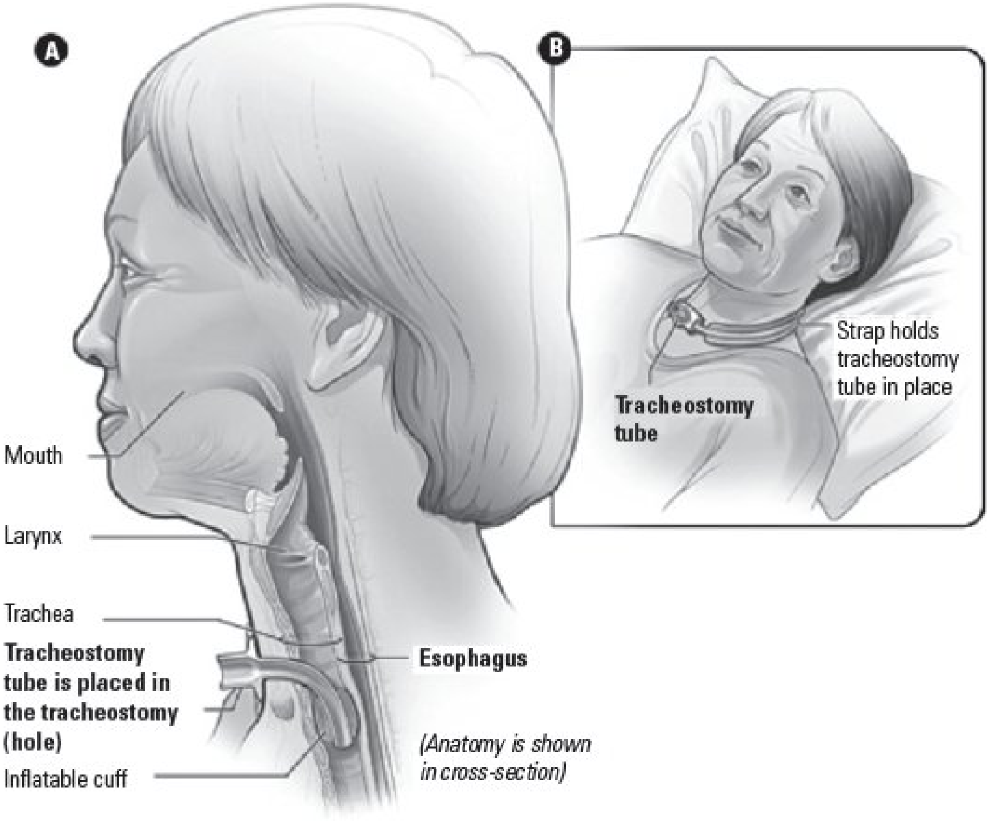
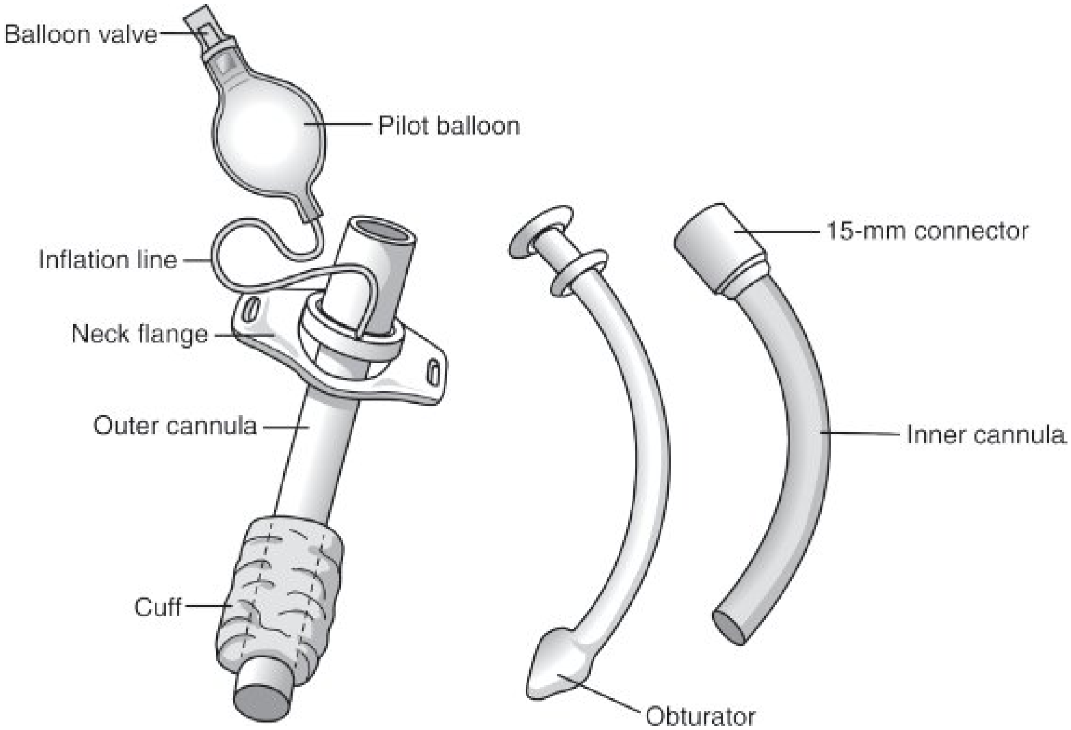

A
B
Strap holds tracheostomy tube in place
Tracheostomy tube
Mouth
Larynx
Trachea
Tracheostomy tube is placed in the tracheostomy (hole)
Esophagus
(Anatomy is shown in cross-section)
Inflatable cuff

Figure 5-2. Parts of a Tracheostomy Tube


Balloon valve
Pilot balloon
Inflation line
Neck flange
Outer cannula
Cuff
15-mm connector
Inner cannula
Obturator

The risk factors include:

- Loose tube ties
- Insufficient length of tracheostomy tube for patient anatomy
- Soft-tissue or airway edema
- Obesity
- Excessive movement of the tube because of inadequate sedation and patient agitation
- Persistent coughing
- The tube being pulled because of the weight of an unsupported ventilator circuit

- The surgical technique used for tracheostomy can be a predisposing factor if the tracheostomy incision is too big for the tube size used

A. Management

It takes about 7 to 10 days for the stoma to heal and the tracheostomy tract to remain open or mature. If the tube is dislodged or accidentally removed before that time, the stoma and tissue planes can easily collapse. An attempt to reinsert the tube blindly will likely be unsuccessful because of the risk of creating a false lumen. Therefore, the dislodgement of the tracheal tube during the first week post-procedure is a medical emergency and should be treated as such.

If a tube is removed during the first week after tracheostomy, blind placement should not be attempted through the tract. Equipment and supplies, including oxygen bag-mask, suction catheter, and laryngoscope or bronchoscope should be immediately requested to insert an endotracheal tube by the supraglottic (oral or nasal) route to secure the airway first before any attempts to reinsert a new tracheostomy tube under controlled conditions.

When a suction catheter cannot be inserted through the tracheostomy tube beyond the tube (5–7 cm), it could be a sign of dislodgement, indicating that the tube could be in a false passage or obstructed by a mucus plug (discussed in next section).

> !
>
> *Consider bag-valve-mask ventilation and intubation (oral or nasal) if a new tracheostomy (within 7 days) is accidentally dislodged because reinsertion through the stoma may be difficult.*
>
> !

When suspecting a false tract, the provider should not forcefully manually bag ventilate the patient through the suspected dislodged tube, especially when significant resistance is felt during bagging. Forceful bagging can push air into the subcutaneous tissues and cause subcutaneous emphysema and crepitus in the neck, face, and upper chest area. This subcutaneous air can make securing the airway more difficult.

B. Preventive Measures

It is essential to secure the tracheostomy adequately to avoid accidental dislodgement.

In the postoperative period, the management of a tracheostomy can help prevent tube dislodgements and avoid potentially catastrophic consequences. Such measures include keeping tracheostomy ties secure and tight (no more than a single finger should fit under the ties), removing any traction to the ventilator tubes and circuit, keeping the tracheostomy tube in the midline and neutral position, minimizing transport of the patient as much as possible, and adequate sedation to avoid excessive coughing or agitation by the patient.

When the tracheostomy tube is completely removed from the stoma (decannulation) and if the stoma is not matured (less than a week old), then the likelihood of successful tube reinsertion without causing a false lumen is very low. Therefore, the immediate treatment of decannulation in an immature stoma is bag-mask ventilation and endotracheal intubation (ETI).

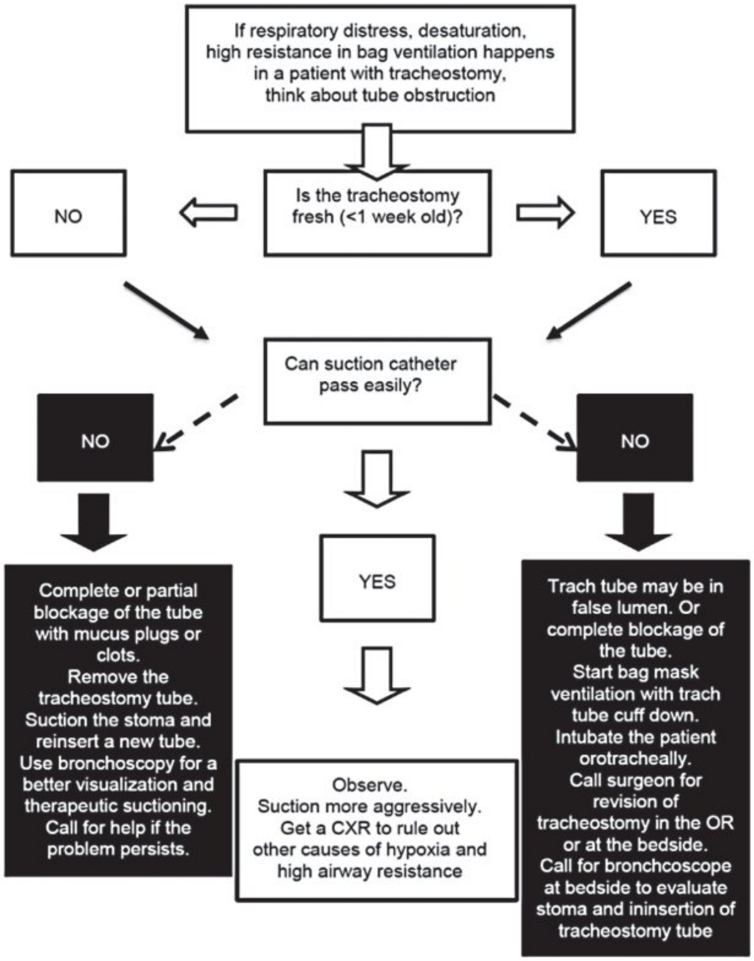
C. Tube Obstruction: Mucus Plugging, Tube Malfunction

If a tracheostomy is in the right place, but a patient still has trouble breathing, see whether anything is plugging the tube or not.

When a patient with a tracheostomy tube is in respiratory distress, the first step is to rule out any obstruction of the tube. To do so, remove the inner cannula and make sure it is patent. If the cannula is clogged with secretions, debris, and mucus plugs, it should be cleaned and replaced with a new one. If the patient continues to be in distress, an attempt to pass a suction catheter down the tracheostomy tube must be made. If the catheter easily passes and tracheal secretions can be suctioned, the tube is properly in place, and a primary patient problem should be pursued. If there is resistance during the passage of the suction catheter, but the catheter can be passed through, the tube may be partially obstructed with secretions.

Conversely, if a suction catheter cannot be passed at all or cannot be passed beyond the length of the tracheostomy tube, consideration should be given to a completely obstructed tube with thick dried secretions or a tube that is lodged in a false lumen. The management at this point depends on the maturity of the stoma. If the stoma is more than a week old (mature), then the entire tracheostomy tube must be removed and replaced. If the stoma is fresh (less than a week old), then bag-mask ventilation with a deflated cuff (or removed) tracheostomy tube is the safest intervention, followed by ETI and revision of the tracheostomy later under a controlled condition. The algorithm for managing tube obstruction is shown in **Figure 5-3**.

Figure 5-3. Tracheostomy Tube Obstruction Troubleshooting


If respiratory distress, desaturation, high resistance in bag ventilation happens in a patient with tracheostomy, think about tube obstruction
Is the tracheostomy fresh (<1 week old)?
NO
YES
Can suction catheter pass easily?
NO
NO
YES
Complete or partial blockage of the tube with mucus plugs or clots. Remove the tracheostomy tube. Suction the stoma and reinsert a new tube. Use bronchoscopy for a better visualization and therapeutic suctioning. Call for help if the problem persists.
Observe. Suction more aggressively. Get a CXR to rule out other causes of hypoxia and high airway resistance
Trach tube may be in false lumen. Or complete blockage of the tube. Start bag mask ventilation with trach tube cuff down. Intubate the patient orotracheally. Call surgeon for revision of tracheostomy in the OR or at the bedside. Call for bronchcoscope at bedside to evaluate stoma and ininsertion of tracheostomy tube

Information taken from Morris LL, Whitmer A, McIntosh E. Tracheostomy Care and Complications in the Intensive Care Unit. *Critical Care Nurse*. 2013;33(5):18-29.

D. Bleeding: Stoma Hemorrhage, Tracheoinnominate Artery Fistula

One of the perioperative complications of a new tracheostomy is stoma hemorrhage. A small amount of bleeding after the procedure is expected and usually self-limited, but if bleeding at the site continues and is excessive, it should be a serious concern. In such circumstances, the surgeon should be contacted as soon as possible while attempting to stop bleeding by applying local pressure.

Another rare but most deadly complication is a tracheoinnominate artery fistula. In this situation, the innominate artery is eroded through the trachea, causing severe bleeding resulting in exsanguination or suffocation as a result of blood clot formation in the airway and aspiration of blood into alveoli. Risk factors for this complication that often happens 3 to 4 weeks after tracheostomy are:

- Pressure necrosis from high pressures tracheostomy tube cuffs
- Improper placement of the cannula tip (being pulled due to direct weight of the ventilator circuit)
- Hyperextension of the head causing pressure on the trachea from the tip of the tube
- Radiotherapy of the neck
- Prolonged use of a corticosteroid

!

In the case of a tracheoinnominate fistula, overinflate the cuff, provide intubation and direct digital compression, and call surgeons for repair.

!

Although this is an infrequent complication (a reported incidence of 0.7%), the mortality rate is almost 100%. Successful management requires quick thinking and immediate action, including overinflation of the cuff to tamponade the hemorrhage, and translaryngeal intubation for oxygenation with direct digital compression, followed by immediate surgery for repair. Another treatment option could be endovascular embolization.

III. POSTOPERATIVE NECK HEMATOMA

Formation of a neck hematoma (NH) compressing the upper airway may occur after various neck surgeries (**Table 5-1**). A retropharyngeal hematoma may occur after anterior cervical spine surgery.

Many NHs can be treated conservatively, but the patient should be monitored for signs of airway and hemodynamic compromise. A hematoma that is rapidly expanding may directly compress the tracheal lumen below the level of the cricoid cartilage or cause supraglottic edema because of venous and lymphatic congestion, or both. Symptoms may be absent until the lumen is <5 mm, but compression may rapidly become life-threatening. In these circumstances, there is a need for emergency airway management and reoperation.

Table 5-1 Common Neck Procedures in which Postoperative Hematomas May Occur

- Carotid endarterectomy
- Thyroidectomy
- Parathyroidectomy
- Cervical spine surgery
- Cricopharyngeal dysfunction and Zenker diverticulum correction
- Laryngectomy
- Tracheostomy
- Neck cancer
- Trauma of the neck

Emergency reintubation may be difficult because of a small tracheal lumen, tracheal deviation, and laryngeal edema. Multiple intubation attempts may result in oropharyngeal and laryngeal edema or bleeding, further complicating visualization of upper airway anatomy.

!

The key to the management of a postoperative neck hematoma includes early detection, close observation, airway management, and appropriate surgical intervention.

!

At pressures of 257 mm Hg, equivalent to the maximum possible pressure in the neck (ie, systolic blood pressure), there was an average compression of 20.8% of the original anterior-posterior tracheal diameter. Pressures in hematomas observed after neck surgery would be insufficient to cause airway obstruction due to direct pressure on the trachea. Therefore, the most likely cause of airway obstruction would be supraglottic edema secondary to venous obstruction.

Respiratory compromise and airway obstruction may occur after anterior cervical spine surgery. Symptoms developed, on average, 36 hours postoperatively, attributable to pharyngeal edema.

Risk factors for airway complication are:

- Exposing more than three vertebral bodies
- Blood loss >300 mL
- Exposures involving C2, C3, or C4
- Surgical time >5 hours

Myelopathy, spinal cord injury, pulmonary problems, smoking, anesthetic risk factors, and the absence of a drain did not correlate with an airway complication.

A. Characteristics of Postoperative Neck Hematomas by Procedures

1. Carotid Endarterectomy

Carotid hematoma after carotid endarterectomy (CEA) is a devastating and relatively common complication, although the incidence of significant hematoma is reduced. A 10-year retrospective analysis identified patients requiring airway management for neck exploration within 72 hours after CEA. Neck exploration for hematoma was required in 1.4% of patients, and most of these required airway management immediately before neck exploration surgery. The average interval between the completion of CEA and return to the operating room for hematoma evacuation was 6.0 hours. Tracheal intubation was accomplished with both fiberoptic visualization and direct laryngoscopy. In instances of poor direct visualization of the glottis, decompression of the airway by opening of the surgical incision may facilitate intubation of the trachea.

2. Cervical Endocrine Surgical Procedures

Airway compromise from postoperative neck hematoma remains the most feared complication after cervical endocrine surgical procedures, such as thyroidectomy and parathyroidectomy. These events are rare but potentially lethal because of the potential for airway compromise, leading to hypoxia and cardiorespiratory arrest. Critical decision-making is required to simultaneously protect the airway, manage the wound, and control the bleeding. Reintubation can be more challenging than the initial intubation. If neck swelling is recognized, the patient should be evaluated quickly for symptomatology suggestive of airway compromise, such as hypotension or hypoxia.

3. Cricopharyngeal Dysfunction and Zenker Diverticulum Surgery

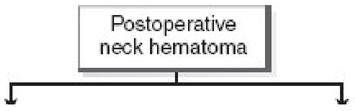
After cricopharyngeal dysfunction and Zenker diverticulum surgery correction, a drain is left for 24 hours to avoid hematomas in the neck region. One of the complications of the procedure may be the development of hematomas of the cervical region that can jeopardize the airway patency and require immediate surgical revision.

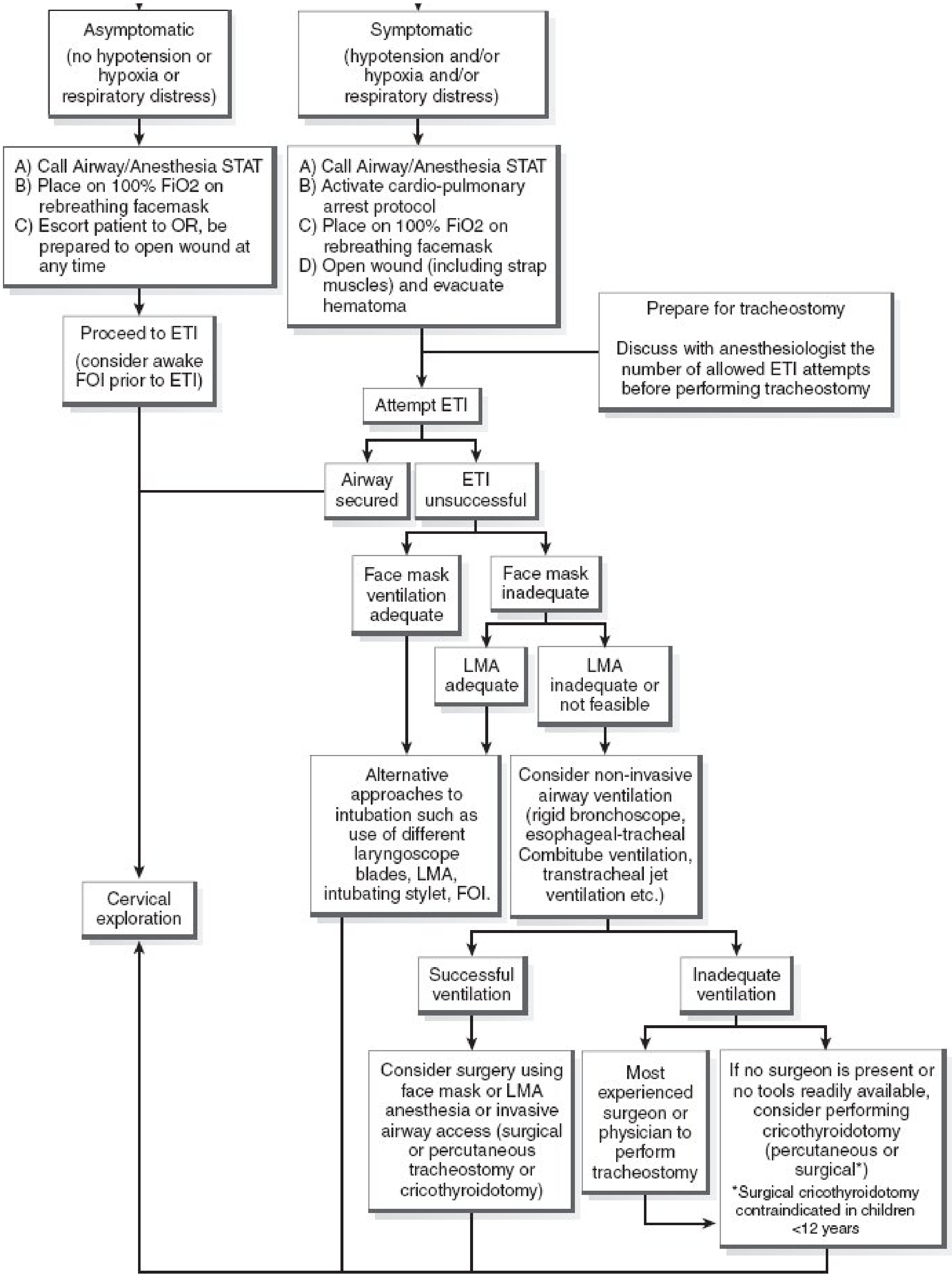
B. Management

The first 12 hours are the most critical in managing a patient after CEA surgery. In addition to the usual care required for a patient recovering from general anesthesia, the essential factors are observation of the patient’s neurologic status, blood pressure control (either hypotension or hypertension must be appropriately treated), and close wound observation. An expanding hematoma should be identified early, and the patient should be returned promptly to the operating room to identify the bleeding source and evacuation of the hematoma.

Bleeding is a potentially fatal postoperative complication following central compartment neck surgery and occurs in less than 2% of cases. Reoperation for bleeding is an objective measure of this complication and is a quality indicator in thyroid and parathyroid surgery. The suggested algorithm for the management of the airway after a postoperative NH is shown in **Figure 5-4**.

Figure 5-4. Algorithm for Airway Management after Postoperative Neck Hematoma




Asymptomatic (no hypotension or hypoxia or respiratory distress)
Symptomatic (hypotension and/or hypoxia and/or respiratory distress)
A) Call Airway/Anesthesia STAT
B) Place on 100% FiO2 on rebreathing facemask
C) Escort patient to OR, be prepared to open wound at any time
A) Call Airway/Anesthesia STAT
B) Activate cardio-pulmonary arrest protocol
C) Place on 100% FiO2 on rebreathing facemask
D) Open wound (including strap muscles) and evacuate hematoma
Prepare for tracheostomy
Discuss with anesthesiologist the number of allowed ETI attempts before performing tracheostomy
Proceed to ETI (consider awake FOI prior to ETI)
Attempt ETI
Airway secured
ETI unsuccessful
Face mask ventilation adequate
Face mask inadequate
LMA adequate
LMA inadequate or not feasible
Alternative approaches to intubation such as use of different laryngoscope blades, LMA, intubating stylet, FOI.
Consider non-invasive airway ventilation (rigid bronchoscope, esophageal-tracheal Combitube ventilation, transtracheal jet ventilation etc.)
Cervical exploration
Successful ventilation
Inadequate ventilation
Consider surgery using face mask or LMA anesthesia or invasive airway access (surgical or percutaneous tracheostomy or cricothyroidotomy)
Most experienced surgeon or physician to perform tracheostomy
If no surgeon is present or no tools readily available, consider performing cricothyroidotomy (percutaneous or surgical*)
*Surgical cricothyroidotomy contraindicated in children <12 years

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The American Society of Anesthesiologists (ASA) has developed guidance for airway management in this setting. If the patient is cooperative, stable, and able to maintain spontaneous breathing, airway patency, and adequate oxygen saturation, awake intubation is recommended. Should a life-threatening obstruction occur, personnel who are able to perform a surgical airway should be prepared to intervene immediately. Suspicion that the postoperative NH is expanding may be an indication to open the wound. Spontaneous ventilation should be maintained with the induction of general anesthesia. The tracheal tube should be placed below the level of the obstruction and may require fiberoptic confirmation. Use of a supraglottic airway device is not recommended. Video-assisted laryngoscopy and flexible scope intubation can be helpful choices if they allow airway visualization.

C. Risk Factors for Postoperative Neck Hematoma

In one recent prospective comparative study, perioperative clopidogrel, combined with aspirin, was not associated with greater bleeding complications across all categories of major arterial surgery. Vascular surgeons are regularly confronted with complex decisions concerning the cessation or continuation of clopidogrel because an increasing number of vascular patients are on dual antiplatelet therapy (APT).

The main factors associated with reintervention were:

- Previous APT
- Non-patch surgical techniques
- Neurologic instability (shunt use), probably associated with less accurate hemostasis

Global bleeding is related to the use of P2Y12 inhibitors (ie, clopidogrel) preoperatively. Postoperative hypertension is also associated with a higher risk of bleeding. The relationship between airway management technique to patient outcome has not been systematically studied.

The routine use of an intraoperative drain has not been shown to reduce the incidence of postoperative neck hematoma. Bleeding rarely occurs from the suture line. More often, a diffuse ooze is present, requiring reversal of anticoagulation. Drainage of the hematoma and correction of its cause prevent chronic draining wounds, infection, and the rare occurrence of pseudoaneurysm formation. The last issue is more frequent when vessel closure is performed with patch angioplasty.

Given the paucity of evidence-based guidelines on the appropriate use of perioperative clopidogrel, there appears to be an apparent lack of consensus among vascular specialists on this issue. A 2009 survey of 399 European surgeons found that 43% and 55%, respectively, would stop the P2Y12 inhibitor before CEA for symptomatic and asymptomatic patients.

Antiplatelet/anticoagulant drugs and coagulopathies groups are reported to be risk factors for NHs requiring reoperation after thyroidectomy. The rate of NH after thyroidectomy is increased four fold in patients of both groups. No significant differences for the subgroups of low-dose aspirin, P2Y12 inhibitors, prophylactic heparin use, and coagulopathies group were reported.

> *Anticoagulation/antiplatelet therapy is one of the risk factors for postoperative NH.*

The subgroup receiving vitamin K antagonists (eg, warfarin) reported a tenfold higher incidence than the control group. Half of the NHs reported in both groups developed after 24 hours from surgery. A strict postoperative and post-discharge surveillance is mandatory for these patients, given the late NH occurrence. Outpatient surgery is contraindicated.

Protamine reduced serious bleeding in patients that had used heparin before or during surgery and requiring reoperation during CEA without increasing the risk of myocardial infarction, stroke, or death.

D. Therapy

> *Incising surgical sutures to decompress the NH at the bedside should be considered if the patient's airway is immediately threatened.*

A clearly defined, sequential approach to a patient with NH is critical because preoxygenation may be difficult. Any delay in securing the airway may lead to rapidly progressing hypoxemia. If the patient is completely asymptomatic, the surgical team should be informed, the patient should be taken to the operating room for wound exploration, and staff should be on high alert to open the wound at bedside if the patient becomes symptomatic. If the patient is symptomatic upon initial evaluation, it is advisable to actively manage the patient's airway and breathing by bag-valve-mask, ETI, and possible cricothyroidotomy while simultaneously decompressing the hematoma by incising the sutures, including those approximating the strap muscles. This often can be done either by the on-call surgical team or under their direction. No local anesthetic is needed, and sterile technique (gloves and topical preparation) should be used as urgency permits. The number of ETI attempts allowed before switching to a different technique should be discussed (no more than two, according to the guidelines from the Difficult Airway Society).

! *Be prepared for cricothyroidotomy when securing the airway of a patient with a NH.* !

If the ETI is unsuccessful and the face mask and laryngeal mask airway are inadequate for maintaining ventilation and oxygenation, other noninvasive airway ventilation techniques should be considered (eg, rigid bronchoscope, esophageal-tracheal Combitube ventilation, transtracheal jet ventilation). If all of the techniques listed previously fail, the most qualified provider should perform an emergency cricothyroidotomy.

If the emergency setting is outside of the operating room, the first responder to a patient with a NH may have limited experience obtaining a surgical airway. An emergency surgical airway can be difficult but is usually preferred despite potential complications. Most providers cannot perform this maneuver effectively within 3 minutes and will take longer. In this situation, a delayed surgical airway can result in the death of the patient. Cricothyroidotomy can be performed via a percutaneous or surgical approach. The current airway management guidelines of the "can't intubate-can't ventilate" scenario include using cannula cricothyroidotomy with percutaneous transtracheal jet ventilation or using surgical cricothyroidotomy.

IV. ANGIOEDEMA

Case Study

A 64-year-old African American woman arrives at the emergency department (ED) reporting swelling of the tongue and subjective dyspnea of abrupt onset. Her medical history includes type 2 diabetes mellitus, hypertension, and diastolic congestive heart failure with prescriptions of beta-blockers and an ACE inhibitor for many years; in addition, her surgical history consists of a non-diagnostic exploratory laparotomy 20 years ago. Evaluation of the patient reveals a limited view of the oral cavity because of tongue swelling, but no stridor or dysphonia is present initially. Pulse oximetry and vital signs are normal. The patient received therapy with H2 blockers, short-acting nebulized bronchodilators, and systemic steroids. Two hours later, the patient has no symptomatic improvement and now has drooling and increasing anxiety.

While waiting for the Ear-Nose-Throat service on-call, the patient receives racemic epinephrine, and preparations are made for a difficult airway/surgical airway situation.

- What is the cause of this upper airway obstruction scenario?
- Why has the standard therapy failed to prevent progression and clinical deterioration?
- What is the appropriate pharmacologic intervention if the patient does not require an artificial airway yet?

Incidence

Angioedema (AE), also referred to as angioneurotic edema, is a complication with potential life-threatening consequences since the initial recognition by Osler of hereditary AE (HAE) in 1885. The early recognition and management of AE are of great importance to the practitioner in the acute setting and for those in the ED and the perioperative setting.

!

Recognize AE as one of the differential diagnoses of upper airway obstruction.

!

The population affected is mostly older individuals and African Americans (AA) in origin. AE has increased in prevalence according to the Nationwide Emergency Department Sample (NEDS) 2006–2010 from 29.3 to 35.8 of 100,000 people. Data obtained from the National Inpatient Samples (NIS) 2000–2009 showed an increase in total hospitalizations associated with AE, from 3.4 per 100,000 to 5.4 per 100,000, and increased hospitalization rates for individuals of AA origin.

Among hospitalized patients with significant drug-induced AE, the condition is associated with cardiovascular and antihypertensive agents, particularly angiotensin-converting enzyme inhibitors (ACEIs) and angiotensin receptor blockers (ARBs), even if the drug has been taken for years.

A. Pathophysiology and Classification

AE is the clinical manifestation of edema in the subcutaneous and submucosal tissues as a result of increased vasodilation and vascular permeability. This process is triggered by inflammatory activation using a histamine-mediated pathway (HMP) or a bradykinin-mediated pathway (BMP). The presentation of urticaria/wheals is generally associated with activation of the HMP while its absence is associated with activation of BMP.

The pathophysiology of AE depends on the inflammatory pathway activated.

- HMP: Typically represented by Type1 hypersensitivity reaction, upon presentation of an antigen to T-cells (CD4-TH2), stimulates B-cells to synthesize immunoglobulins, particularly IgE antigen-specific with the release of histamine and on a late phase response, leukotrienes, and others. This usually occurs within seconds or minutes after exposure in the initial stage.
- BMP: The release of bradykinin, a vasodilatory mediator, promotes endothelial cell activation and, consequently, tissue edema. Bradykinin is released by multiple cells. The mechanisms that promote its production and prevent its degradation can cause AE. Bradykinin production is

directly associated with activation of the coagulation cascade, contact, or complement pathways.

The classification of AE is related to the clinical presentation and the underlying mechanism involved in the inflammatory response, as defined in **Table 5-2**.

Table 5-2 Angioedema Classification

- AE with urticaria/wheals (associated with activation of the HMP)
  - Allergic
  - Associated with acute or chronic urticaria
  - Others (ie, stress urticaria, exercise-induced urticaria, associated with NSAIDs)
- AE without urticaria/wheals (associated with activation of BMP)
  - Hereditary AE (HAE)
  - HAE due to C1-INH deficiency (Type 1 & 2)
  - HAE with normal C1-INH
  - Acquired AE - associated with C1-INH deficiency
  - Acquired AE - associated with medications (ie, ACEI/ARB)
- Idiopathic AE
- Pseudo AE/AE-mimics

Abbreviations: HMP, histamine-mediated pathway; AE, angioedema; BMP, bradykinin-mediated pathway

B. Diagnosis

The initial evaluation and medical history of the patient are essential in the approach to the patient with AE. Prior medical history, age of the first event, ethnicity, drug exposure, and family history are relevant.

In women, evaluation of the prescription of hormonal therapy (oral contraceptive pill, hormone replacement therapy) and pregnancy status are important. In the perioperative setting, a history of prior adverse drug effect, prior diagnosis of HAE, and chronic therapy and compliance are important because advanced preparation of the perioperative period is fundamental. AE can occur in patients without known drug allergies.

In addition, special populations with special needs or therapies, ie, patients with hypertension/congestive heart failure and therapies associated with the use of

ACEI/ARB, in the pregnant patient, in labor, or breastfeeding, calls for the need for alternative maintenance preventive medication in case of HAE.

Triggers associated with HAE attacks include:

- Trauma
- Medical procedures
- Use of estrogen-containing agents
- ACEI/ARB
- NSAIDs

C. Clinical Manifestations

The clinical manifestations of AE are dependent on the mediator pathway induced by the trigger cause. The histamine pathway activation is related to a history of atopy, episodes of anaphylaxis, urticaria, or drug sensitization. If activation of the bradykinin pathway is suspected, it is vital to evaluate family history (ie, HAE), history of malignancy, and the use of known trigger drugs, in particular, ACEIs and ARBs.

Symptoms associated with AE include:

- Urticaria (more frequent with HMP) (with pruritus or not)
- Swelling of larynx, tongue, lips, eyelids (dysphonia, dysphagia, drooling)
- Swelling of distal extremities and urogenital (more frequent with BMP)
- Abdominal pain (more frequent with BMP)

The evaluation of patients with AE in the emergency setting would benefit in the grading of severity because this aids in assessing risk and influences appropriate disposition.

The suggested staging scale is divided into four stages. The clinical manifestations correlate with the necessity of a higher level of care.

- Stage I presents as facial rash, facial edema, and lip edema, with outpatient treatment.

- Stage II presents as soft palate edema and is treated on the hospital floor.
- Stage III presents as tongue edema and most often requires ICU level of care.
- Stage IV presents as laryngeal edema and requires ICU treatment. Patients in this stage are more likely to require an artificial airway.

The evaluation of drug-induced AE relies on identifying drug exposure and clinical presentation (time of onset, drugs used, the potential for pharmacologic interaction, etc). An example is the use of NSAIDs, more likely associated with histamine pathway activation, in contrast to the use of ACEI/ARB alone or in association with others (ie, rTPA) and is associated with activation of the bradykinin pathway.

Finally, recognizing pseudoangioedema in patients with swelling that resembles AE is very important because it impacts the management and subsequent prognosis. Examples of pseudoangioedema are acute contact dermatitis, drug rash with eosinophilia and systemic symptoms (DRESS), hypothyroidism, superior vena cava syndrome, and subcutaneous emphysema, among others.

D. Pharmacologic Management

In all cases, consideration should be given to performing a laboratory diagnostic work-up. It is suggested to evaluate IgE levels, tryptase concentration, C4 concentration, C1q level, C1INH concentration, and C1INH function studies.

> !
>
> *Secure the airway first for life-threatening upper airway obstruction due to AE and then consider pharmacotherapy.*
>
> !

AE is an emergent, life-threatening situation. To address upper airway obstruction, the application of the Upper Airway Emergency Protocol is recommended (see Section V - EMERGENCY SURGICAL AIRWAY). Once the airway has been evaluated and secured, in addition to hemodynamic stabilization, if necessary, the patient would benefit from standard therapy based on epinephrine, anti-histaminic (H1 and H2 blockers), and systemic steroids.

Pharmacologic agents commonly used for the therapy of AE associated with histamine release are:

1. Epinephrine

In the patient with hemodynamic instability or with manifestations of upper airway compromise, the administration of SQ/IM epinephrine in doses of 0.01 mg/kg of a 1:1,000 solution and up to 0.5 mg is warranted.

2. Antihistaminic Therapy

The use of antihistaminic therapy uses both H1 and H2 receptor blockers. H1 blockers, like diphenhydramine (or chlorpheniramine), taking advantage of the availability in IV form, are suggested. Be aware of potential adverse effects such as somnolence, urinary retention, and delirium in susceptible individuals like the elderly. Alternatively, the use of non-sedating H1 blockers is acceptable, if tolerated, and in non-severe cases. The use of H2 blockers is common practice in the acute setting. The use of H2RA with H1 blockers is standard of care to block histamine from multiple pathways.

3. Systemic Steroids

Corticosteroids are of common use for the acute management of AE. In the acute setting, the use of methylprednisolone in doses of 60–120 mg IV is suggested. Oral corticosteroids could be used, if tolerated, in non-severe cases. Individuals allergic to methylprednisolone or prednisone could alternatively benefit from the use of dexamethasone. If the type of AE is not known, there is no contraindication for the administration of epinephrine, antihistamines, and systemic steroids. Bradykinin-mediated AE would typically not respond to the therapy suggested previously, and progression may occur.

4. Specific Therapy

The use of specific therapy in the acute setting is relevant in individuals with HAE Type 1 and 2 (HAE-1 and HAE-2), HAE-nC1INH, and HAE associated with ACEI/ARB. Consensus recommendations for the therapy of these types of HAE in the acute setting are included in **Table 5-3**.

5. Plasma-derived C1INH

C1 esterase inhibitor (human) is indicated for the acute treatment and the prophylactic therapy of HAE in adults and children and the treatment of HAE-C1INH deficiency. The medication is administered intravenously. The adverse drug effects include hypersensitivity (including anaphylaxis), thromboembolic events, and risk of transmission of infectious pathogens from the donor's plasma. This product is obtained from human plasma. Although donations are screened, tested, and inactivated, there is a risk that it may contain infectious agents that can transmit diseases from donor to patient. Patients should be monitored for arterial and venous thromboembolic events, particularly those with preexisting risks from thrombosis like immobility, morbid obesity, and hormone use.

Table 5-3 Drugs Used for Short- and Long-Term Prophylaxis of Hereditary Angioedema

Agents	Indications	Dose	Mechanism*	Adverse Effects
Plasma-derived nano filtered C1 inhibitor	Acute attacks, short- and long-term prophylaxis	1,000 U IV Long-term prophylaxis max 2,500 U q3-4 days	Inhibits plasma kallikrein, coagulation factors XIIa and XIa, C1s, C1r, MASP-1, MASP-2, and plasmin	Rare: anaphylaxis, thrombosis Common: dysgeusia Theoretical; transmission of blood-borne infections
Plasma-derived C1 inhibitor	Acute attacks, short- and long-term prophylaxis	20 U/kg IV		
Recombinant human C1 inhibitor	Acute attacks, short-term prophylaxis	50 U/kg IV Max dose 4,200 U/dose for two doses		Common: rash, pruritus, sinusitis Uncommon: anaphylaxis
Ecallantide	Acute attacks	30 mg SubQ	Inhibits plasma kallikrein, which inhibits the conversion of kininogen to bradykinin	Common: headache, nausea, pyrexia, injection site reaction, prolonged partial-thromboplastin time Uncommon: development of anti-drug antibodies, anaphylaxis
Icatibant	Acute attacks	30 mg SubQ	Bradykinin B2 receptor antagonist	Common: discomfort at injection site, pyrexia, increased LFTs, dizziness
Fresh frozen plasma	Acute attacks Preoperative prophylaxis	IV of 2 units for <90 kg or 3 units for >90 kg		Transmissible diseases and transfusion reactions
Tranexamic acids		20-50 mg/kg/day in 2-3 divided doses	Reduces C11 esterase inhibitor consumption and reduces complement activation	

*MASP denotes mannose-binding lectin-associated serine protease.

6. Ecallantide

Ecallantide is a plasma kallikrein inhibitor that reduces the kallikrein-mediated production of bradykinin. It is indicated and approved for the treatment of acute HAE attacks in patients older than 12 years of age. The administration is by a set of three 10-mg SQ injections under direct supervision; all three injections may be administered in the same or different locations. An additional divided 30-mg dose may be administered within 24 hours if AE persists. Adverse drug effects include hypersensitivity reactions (including anaphylaxis), which can occur in up to 3% of cases. Some patients may develop antibodies to the medication, which may increase the risk of hypersensitivity reactions. Other adverse reactions occurring in ≥ 5% of patients include headache, diarrhea, neutropenia, and pruritus.

7. Icatibant

Icatibant is a selective bradykinin-B2 receptor antagonist which blocks the vascular effects of bradykinin. It is indicated for the acute treatment of HAE in adults older than18 years of age. Expert opinion favors its use in acute AE associated with ACEI/ARB use, particularly if given within the first few hours of symptom onset before swelling has peaked. The administration is by single 30-mg SQ injection, which may be repeated every 6 hours if the patient does not have an adequate response or if symptoms reappear up to a maximum dose of 90 mg per day. It is common for patients to develop an injection site reaction, which occurs in up to 97% of patients. Up to 4% of patients may develop antibodies to the medication. Other adverse effects include increased liver function tests, dizziness, and fever, all of which occur in less than 5% of patients.

8. Fresh Frozen Plasma

In areas where direct therapy is not available, fresh frozen plasma administration may be the only therapy available for acute HAE attacks, including AE associated with ACEI/ARB use. It appears effective in most incidences of bradykinin-mediated AE. Administer an IV of 2 units for <90 kg or 3 units for >90 kg, with repeated dosing, if required. Consideration has to be given to the risk of transmissible diseases and transfusion reactions.

E. Perioperative Management

Plasma-derived C1INH, androgens, and FFP can be used for prophylaxis of AE for patients at high risk.

!

In the setting of perioperative or preprocedural (medical, surgical, or dental), prophylaxis is recommended if any mechanical impact will occur in the upper respiratory/digestive tract of patients with HAE. The drug of choice is the administration of plasma-derived C1INH. Consideration for the administration of fresh frozen plasma (FFP) should be given if resources are limited. These procedures are to be performed in a controlled environment because these interventions are not 100% effective.

In the management of an obstetric patient with HAE, it is advised to prefer vaginal delivery. When needed, an artificial airway can be prepared for difficult airway management, and if a cesarean section is needed, consider the administration of plasma-derived C1INH.

F. Management of Drug-Induced Angioedema

The management of drug-induced AE in the acute setting depends on the assessment of the airway involvement and the recognition of the offending drug and its pathophysiologic action. In the event of drugs triggering the HMP, it is recommended to use the standard acute pharmacologic therapy discussed previously.

- Alternatively, interference with arachidonic acid metabolism (ie, NSAIDs) could trigger AE.
- Drugs interfering with bradykinin metabolism, increasing bradykinin level (ie, rTPA and ACEI/ARB) have the potential for additive adverse effect when used in combination.
- Consideration should be given to the increased risk for AE in patients older than 40 years of age, of African American descent, and females.
- Expert opinion for the treatment of ACEI/ARB-induced AE in the acute setting is the use of icatibant or ecallantide when available.

G. Other Types of Management

Acquired-AE is infrequent with a reported prevalence of 1:100,000 to 1:500,000 in the general population. Clinical manifestations are the same as HAE, although it is often associated with lymphoproliferative disorders or antibodies against C1INH. The treatment in the acute setting is the same as in HAE.

Idiopathic AE refers to patients with clinical manifestation of AE in which no identifiable causality is related to recurrent attacks. Management in the acute setting is standard pharmacologic therapy and supportive care in a monitored environment if indicated.

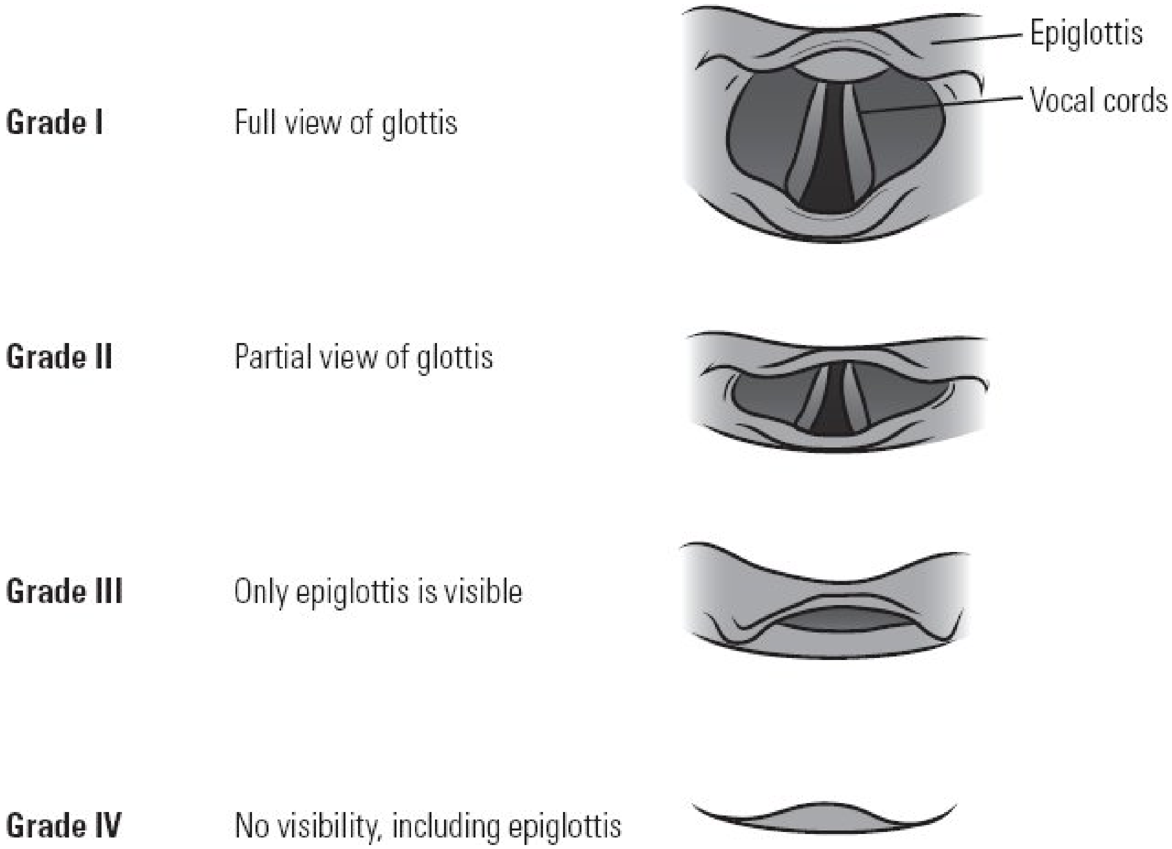
V. EMERGENCY SURGICAL AIRWAY

The emergency surgical airway is indicated in the presence of acute airway obstruction (AAO) or predictably difficult airway (nasal or oral) in addition to the "cannot intubate-cannot ventilate (CICV)" scenario. The situational emergency could significantly compromise the morbidity and mortality associated with the procedure. A multidisciplinary team approach, advanced evaluation, and risk assessment, with appropriate planning (when possible) with more than one initiative available, is recommended.

A. Acute Airway Obstruction

The most common manifestations associated with AAO that could require emergency surgical airway are stridor, dysphagia, hoarseness, dyspnea, neck mass, and pain. In the patient with AAO, in addition to clinical evaluation, the use of direct laryngoscopy (direct visualization vs. indirect video laryngoscopy) or naso-endoscopic evaluation allows an estimate of the level of compromise of the patient's airway (**Figure 5-5**). If possible, imaging via computed tomography or ultrasonography scanning would be helpful if timing and safety allow.

Figure 5-5. Modified Cormack-Lehane Score Classification (Laryngoscopy)


Epiglottis
Vocal cords
Grade I
Full view of glottis
Grade II
Partial view of glottis
Grade III
Only epiglottis is visible
Grade IV
No visibility, including epiglottis

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Before attempting intubation, clinicians should assess the patient's airway to predict the difficulty of intubation. When such difficulties are encountered, surgeons who can implement an emergency surgical airway may need to be on standby. Conditions associated with airway difficulty are listed here.

Abnormal facial anatomy/development

- Small mouth or large tongue
- Dental abnormality
- Prognathia

- Obesity
- Advanced pregnancy
- Acromegaly
- Congenital syndromes

Inability to open mouth

- Masseter muscle spasm (dental abscess)
- Temporomandibular joint dysfunction
- Facial burns
- Postradiotherapy fibrosis
- Scleroderma

Cervical immobility/abnormality

- Short neck/obesity
- Poor cervical mobility (eg, ankylosing spondylitis)
- Previous cervical spine surgery
- Presence of cervical collar
- Postradiotherapy fibrosis

Pharyngeal or laryngeal abnormality

- High or anterior larynx
- Deep vallecula: inability to reach base of epiglottis with blade of scope
- Anatomic abnormality of epiglottis or hypopharynx (eg, tumor)
- Subglottic stenosis

Injury

- Traumatic debris
- Obstructing foreign bodies

- Basilar skull fracture
- Bleeding into airway or adjacent swelling/hematoma
- Fractures of maxilla/mandible
- Cervical spine instability (confirmed or potential)
- Laryngeal fracture or disruption

Infections

- Epiglottitis
- Abscess
- Croup, bronchiolitis
- Laryngeal papillomatosis
- Tetanus/trismus

Connective tissue/inflammatory disorders

- Rheumatoid arthritis: temporomandibular joint or cervical spine involvement, cricoarytenoid arthritis
- Scleroderma
- Sarcoidosis

Endocrine disorders

- Goiter: airway compression or deviation
- Hypothyroidism: acromegaly: large tongue

Data from Lavery GG, Craig TR. Airway management in the critically ill adult. In: Parrillo JE, Dellinger RP, eds. *Critical Care Medicine*. 4th ed. Philadelphia, PA: Elsevier Saunders; 2014:11–30.

The Mallampati classifications are a helpful tool for assessing the potential for difficult intubation (**Figure 5-6**). Any airway obstruction caused by edema of the glottis, fracture of the larynx, or severe oropharyngeal hemorrhage presents an immediate challenge. The restriction of cervical spinal motion in most patients with blunt trauma increases the difficulty of establishing an airway.

Figure 5-7 displays the difficult airway algorithm. The inability to intubate the trachea indicates an alternative airway plan, including a laryngeal mask airway, laryngeal tube airway, or surgical airway. A surgical airway (ie, cricothyroidotomy or tracheostomy) is indicated through the vocal cords. A surgical cricothyroidotomy is a preferable way to establish the airway because it is easier to perform, is associated with less bleeding, and requires less time than an emergency tracheostomy.

Figure 5-6. Mallampati Classifications

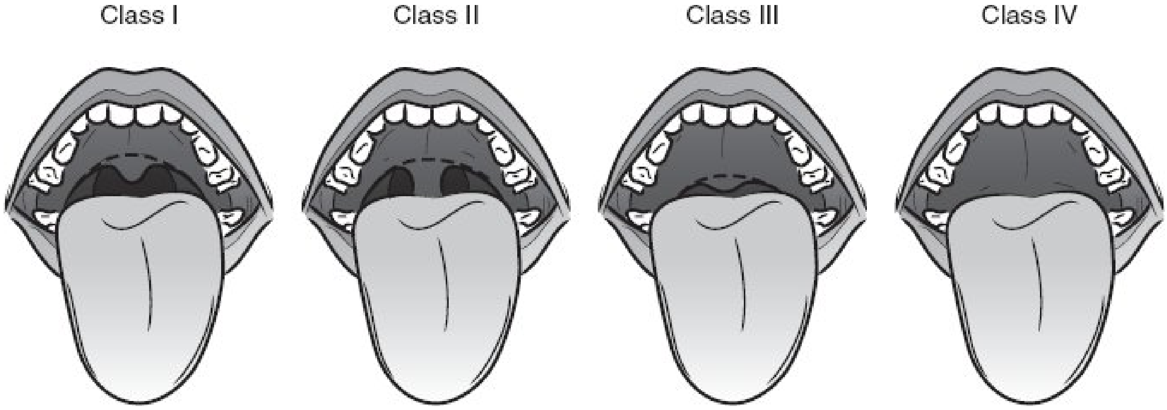

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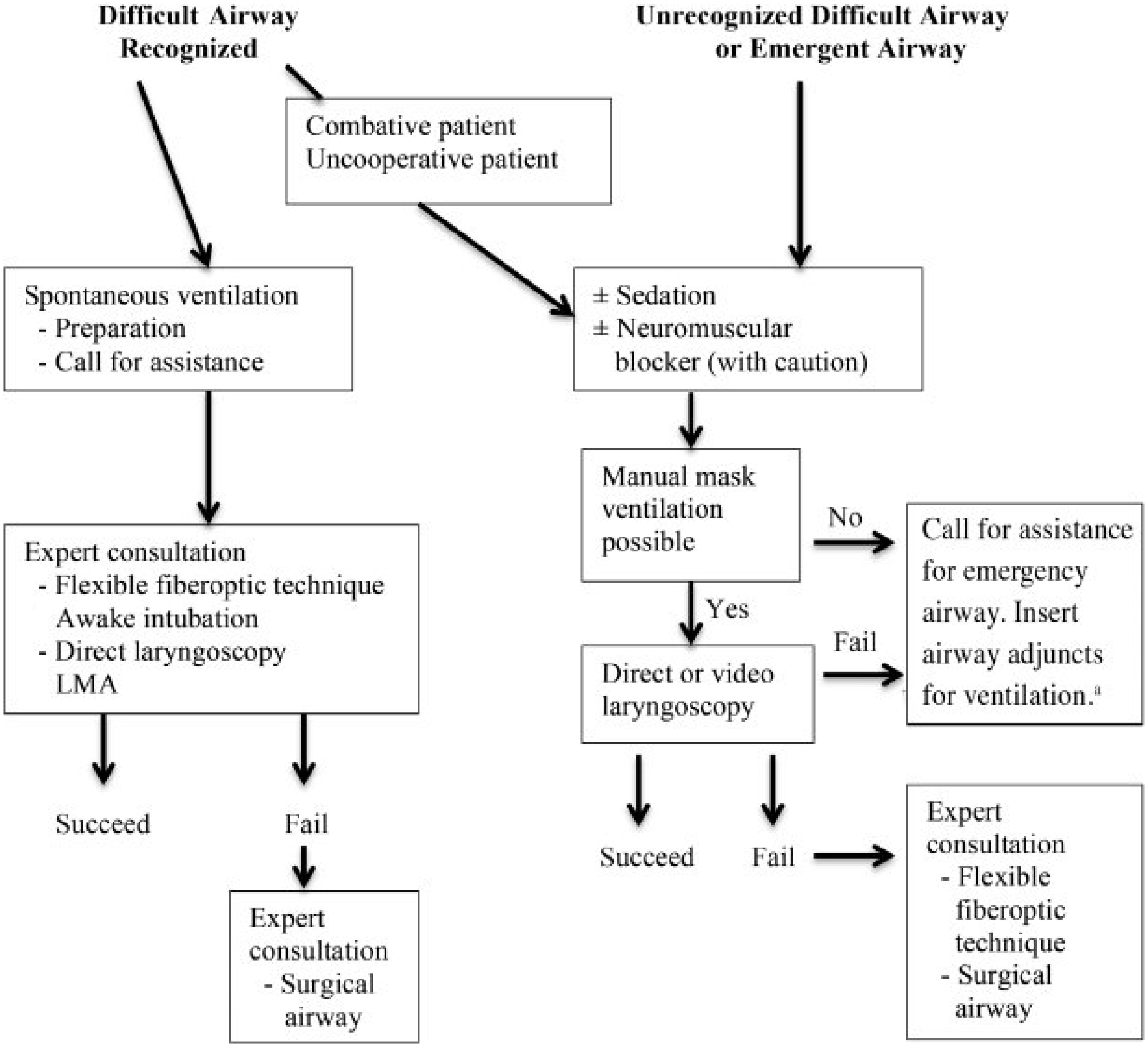
Figure 5-7. Management of the Difficult Airway


Difficult Airway Recognized
Unrecognized Difficult Airway or Emergent Airway
Combative patient
Uncooperative patient
Spontaneous ventilation
- Preparation
- Call for assistance
± Sedation
± Neuromuscular blocker (with caution)
Manual mask ventilation possible
No
Call for assistance for emergency airway. Insert airway adjuncts for ventilation.[a]
Yes
Fail
Direct or video laryngoscopy
Expert consultation
- Flexible fiberoptic technique Awake intubation
- Direct laryngoscopy LMA
Succeed
Fail
Expert consultation
- Surgical airway
Succeed
Fail
Expert consultation
- Flexible fiberoptic technique
- Surgical airway

Abbreviations: LMA, laryngeal mask airway; ET, esophageal-tracheal
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B. “Cannot Intubate – Cannot Ventilate”

To manage the difficult airway, judgment, skill, and teamwork are all critical.

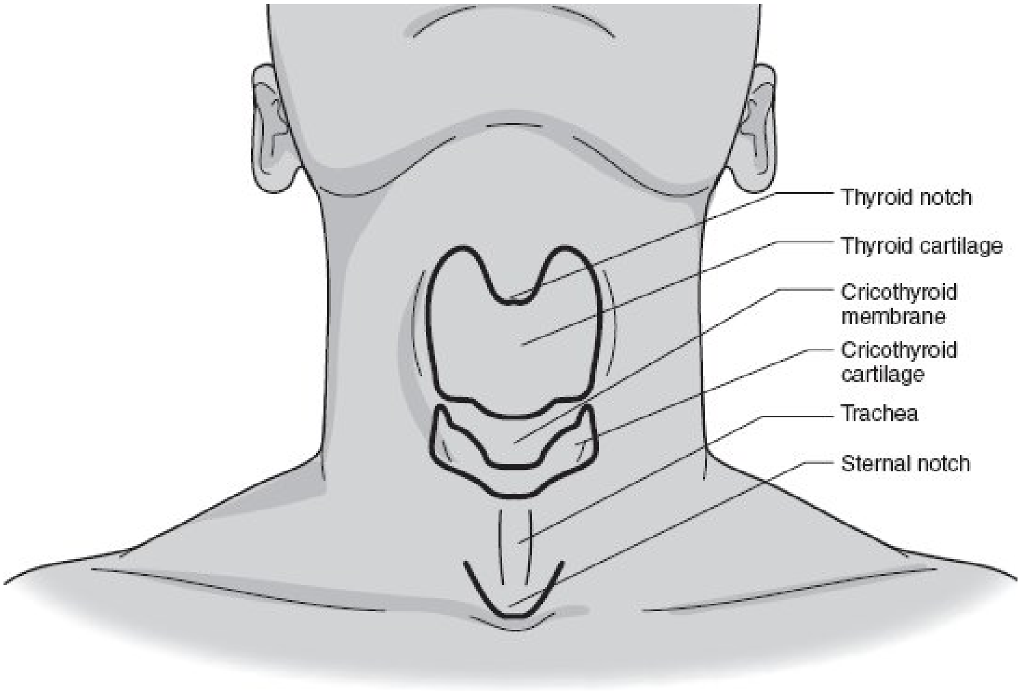
!

"Cannot intubate-cannot ventilate (CICV)" is an uncommon but life-threatening situation. Efficient teamwork with dedicated team members is crucial in overcoming this predicament. Clinicians who are skilled at cricothyroidotomy (needle or surgical) should be involved in the team.

C. Anatomy

The cricothyroid muscles are attached to the cricothyroid membrane, which is diamond-shaped and lies between the thyroid and the cricoid cartilages. In adults, the cricothyroid membrane is 1 centimeter in height and 2 to 3 centimeters wide. The membrane between the cricothyroid muscles is only 1 centimeter. It is critical to recognize the location of the cricothyroid membrane when performing cricothyroidotomy (**Figure 5-8**).

Figure 5-8. Anatomy for Cricothyroidotomy


Thyroid notch
Thyroid cartilage
Cricothyroid membrane
Cricothyroid cartilage
Trachea
Sternal notch

!

Locate the cricothyroid membrane first for the cricothyroidotomy.

!

The cricoid cartilage is the only circumferential structure among other structures composing the trachea. It supports the upper airway and is attached to muscles and ligaments. The vocal cords are attached to the inner anterior part of the thyroid cartilage and located about 1 centimeter cephalad to the upper edge of the cricothyroid membrane.

D. Needle Cricothyroidotomy

Needle cricothyroidotomy is accomplished by inserting a needle through the cricothyroid membrane into the trachea to provide oxygen on a short-term basis (for

30 to 40 minutes) until a definitive airway can be placed. The percutaneous transtracheal oxygenation (PTO) technique is performed by placing a large-caliber plastic cannula (12- to 14-gauge in adults and 16- to 18-gauge in children) through the cricothyroid membrane into the trachea below the level of the obstruction (**Figure 5-9 A** and **5-9 B**). The cannula is then connected to oxygen flow at 15 L/min (50 to 60 psi) with a Y-connector or a side hole cut in the tubing between the oxygen source and the plastic cannula. Intermittent insufflation, 1 second on and 4 seconds off, can be achieved by placing the thumb over the open end of the Y-connector or side hole.

Figure 5-9 A - D. Percutaneous Cricothyroidotomy

Figure 5-9 A. Identify the cricothyroid membrane and the midline. Insert a 14-gauge intravenous cannula and syringe through the skin and membrane. Continuously apply negative pressure until air enters the syringe.

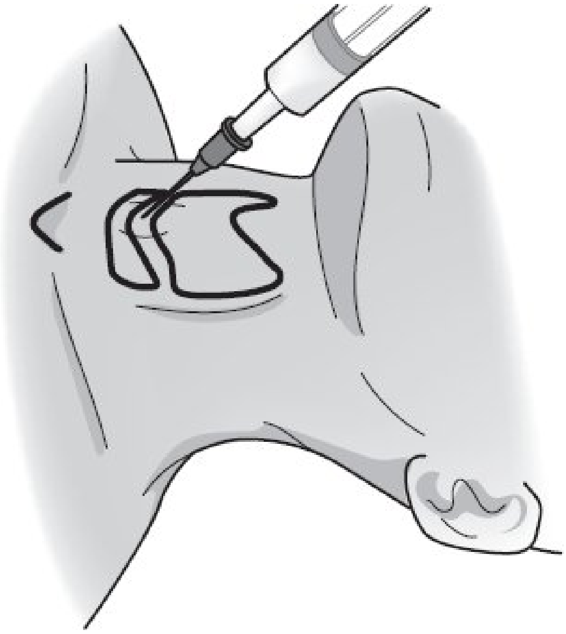


Figure 5-9 B. Stop at this point and push the cannula off the needle into the trachea. Insert the J wire into the cannula advancing only to the estimated level of the carina. Remove the cannula over the wire leaving the wire in place.

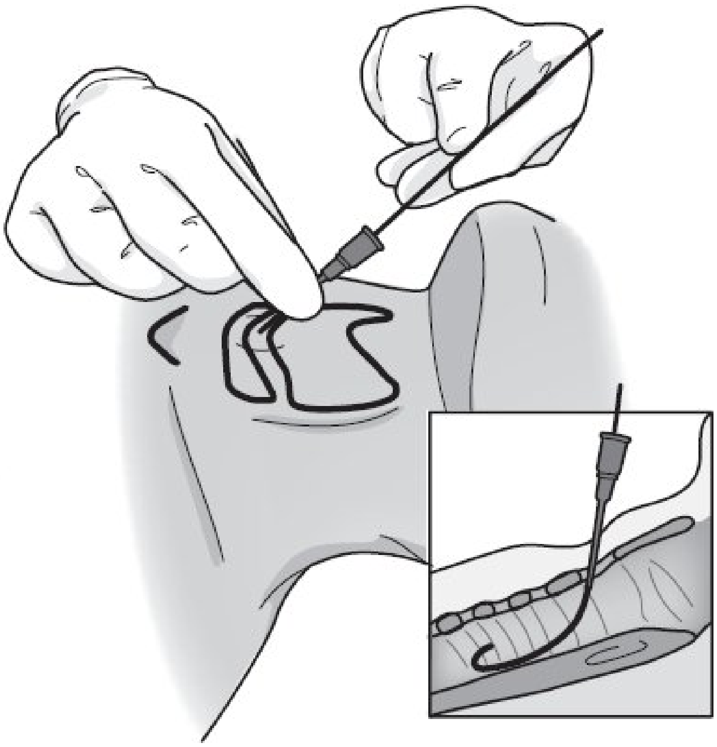


Figure 5-9 C. Thread the cricothyroidotomy cannula on to the J wire and advance into the trachea over the wire in a controlled fashion. Remove the wire assuring it is intact.

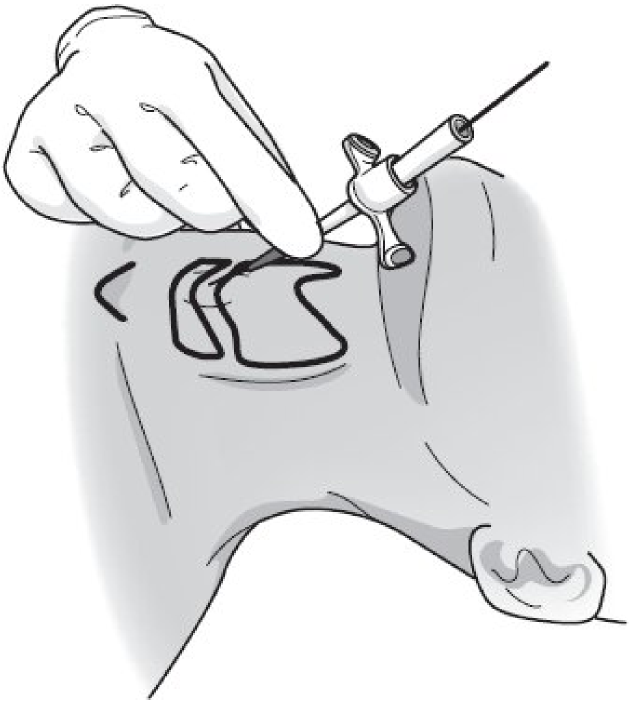
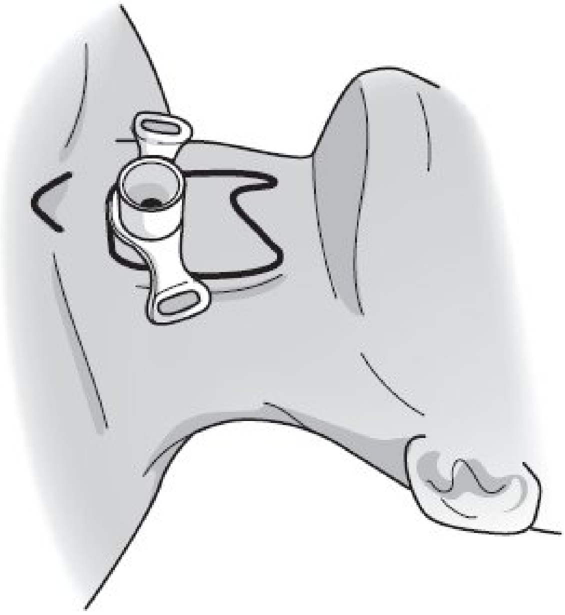


Figure 5-9 D. Secure the cannula adequately. The insertion of the cannula into the trachea allows apneic (low-pressure) ventilation or jet (high-pressure) ventilation.



Of note, the use of PTO should be minimized in patients with head injuries because CO_2 slowly accumulates as a result of inadequate exhalation. Moreover, significant barotrauma, including pulmonary rupture with tension pneumothorax, can occur following PTO if there is complete foreign body obstruction of the glottic area. Careful attention must be paid to the preservation of effective inhalation and exhalation. Commercial kits are available that include small-diameter cannulae with a flange that can be used similar to a tracheostomy tube temporarily (**Figure 5-9 C**, and **5-9 D**).

!

Needle cricothyroidotomy provides a temporal airway. Tracheostomy needs to be followed as a definitive airway.

!

E. Surgical Cricothyroidotomy

> *Surgical cricothyroidotomy with a cuffed endotracheal tube can provide a definitive airway.*

Surgical cricothyroidotomy is accomplished by making a skin incision that extends through the cricothyroid membrane (**Figure 5-10 A-D**). This establishes a definitive airway, which allows positive-pressure ventilation for considerable periods and protects against pulmonary aspiration.

Figure 5-10 A - D. Surgical Cricothyrotomy

Figure 5-10 A. Make a 1.5-cm vertical skin incision over the cricothyroid membrane. (A vertical incision is recommended because it allows the surgeon to extend the incision up and down when the patient's anatomic landmarks are obscured to determine the level of the cricothyroid membrane. Also, it avoids injury to the anterior jugular veins, which are located just lateral to the midline).

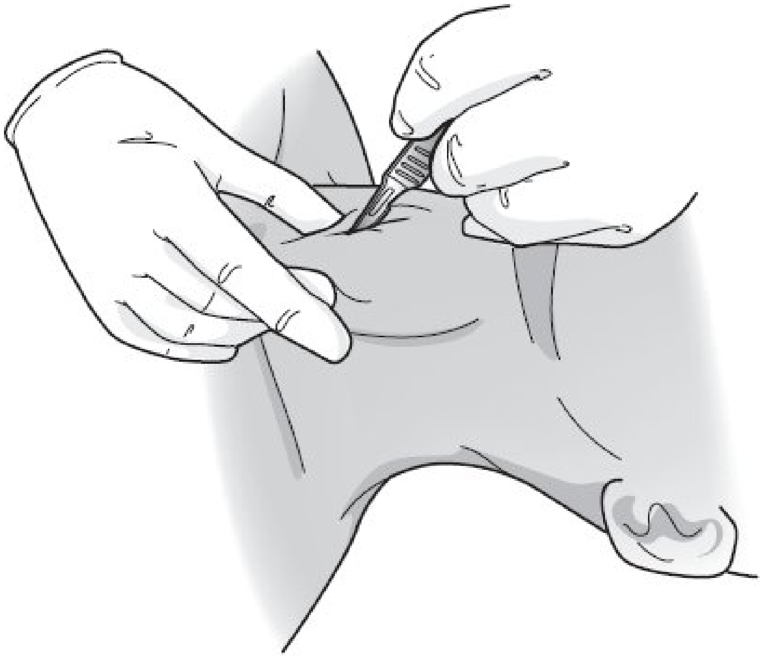


Figure 5-10 B. Incise the superficial fascia and subcutaneous fat.

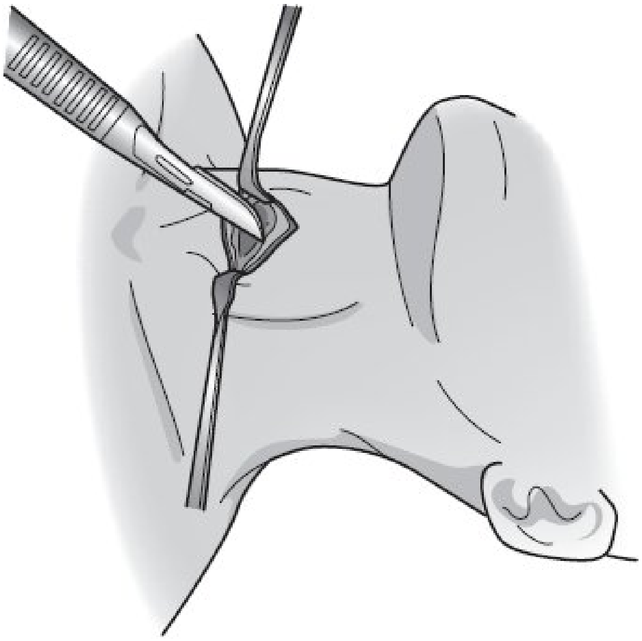


Figure 5-10 C. Divide the cricothyroid membrane transversely with a short blade, blunt forceps, or the handle of a scalpel.

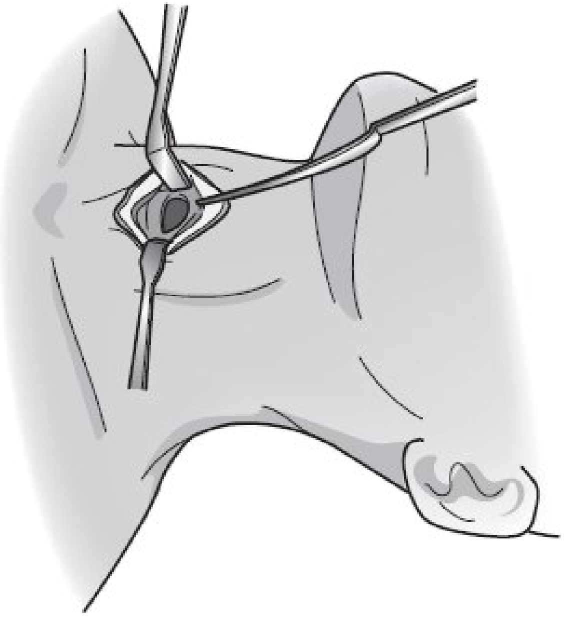
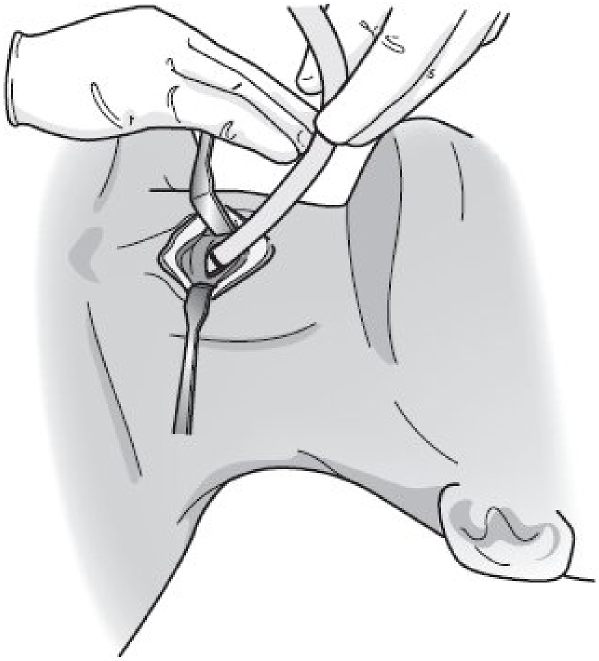


Figure 5-10 D. Insert a small endotracheal or tracheostomy tube (preferably 5- to 7-mm internal diameter) or tracheostomy tube (preferably 5- to 7-mm outer diameter) through the membrane between the thyroid and cricoid cartilages.



!

Choose needle cricothyroidotomy rather than surgical cricothyroidotomy for pediatric patients younger than 12 years of age.

!

When an endotracheal tube is used, it must be adequately secured to prevent malpositioning, such as slipping into the bronchus or complete dislodgement.

For pediatric patients younger than 12 years of age, surgical cricothyroidotomy is not recommended to avoid damage to the cricoid cartilage, which is the only circumferential support for the upper trachea.

Key Points

Surgical Airway Emergencies

- When tracheostomy tube dislodgement or decannulation happens, quick diagnosis and immediate response are the keys to success.
- The age of the stoma following a tracheostomy is the most crucial determinant factor in what course of action is to be taken to secure the airway and deliver adequate oxygenation.
- In cases of rapid expansion of a neck hematoma, the neck incision should be reopened and the clot evacuated before attempting reintubation. Complete airway obstruction may, in extreme circumstances, necessitate emergency cricothyrotomy or tracheostomy.
- Angioedema is one of the airway-threatening events in perioperative patients. It is essential to know the risk factors for angioedema.
- Once symptoms of angioedema are recognized, epinephrine, antihistamines, and steroids are choices for treatment in the acute setting.
- Plasma-derived C1inhibitor is indicated for patients with HAE with C1NH deficiency. The most severe manifestation is upper airway obstruction due to laryngeal edema. If this is the case, the difficult airway algorithm should be followed. Healthcare providers should anticipate an emergency surgical airway.
- Needle or surgical cricothyroidotomy may be necessary for the presence of acute airway obstruction, difficult airway, and “cannot intubate-cannot ventilate” situation. Teamwork with a multidisciplinary team member involving clinicians skilled at airway management is critical.

Suggested Readings

1. Bernstein JA, Cremonesi P, Hoffmann TK, Hollingsworth J. Angioedema in the emergency department: A practical guide to

differential diagnosis and management. *Int J Emerg Med*. 2017;10(1):15.

2. Bove MJ, Morris LL. Complications and emergency procedures. In: Morris LL, Afifi MS, eds. Tracheostomies: The Complete Guide. NY: Springer Publishing Co LLC; 2010:277-302.
3. Christakis I, Perrier ND. Commentary on: Clinical practice algorithm for the treatment of cervical hematoma after an endocrine surgical procedure. *Surgery*. 2016;160(6):1712-1714.
4. Friedman Y, Sobek S. Tracheostomy. In: Parrillo JE, Dellinger RP, eds. *Critical Care Medicine*. 4th ed. Philadelphia, PA: Elsevier Saunders; 2014:202-212.
5. Hagberg CA, Kaslow O. Difficult airway management algorithm in trauma: Updated by COTEP. ASA Monitor 2014; 78:56. Available at www.asahq.org.
6. Lavery GG, Craig TR. Airway management in the critically ill adult. In: Parrillo JE, Dellinger RP, eds. *Critical Care Medicine*. 4th ed. Philadelphia, PA: Elsevier Saunders; 2014:11-30.
7. Maurer M, Magerl M, Ansotegui I, et al. The international WAO/EAACI guideline for the management of hereditary angioedema – the 2017 revision and update. *Allergy*. 2018;73(8):1575-1596.
8. Moellman JJ, Bernstein JA, Lindsell C, et al. A consensus parameter for the evaluation and management of angioedema in the emergency department. *Acad Emerg Med*. 2014;21(4):469-484.
9. Morris LL, Whitmer A, McIntosh E. Tracheostomy care and complications in the intensive care unit. *Crit Care Nurse*. 2013;33(5):18-30.

Suggested Websites

1. https://www.researchgate.net/figure/Suggested-clinical-practice-algorithm-for-management-of-the-airway-in-patients-who_fig1_303597347. Accessed on July 19, 2018.

2. Open Access Atlas of Otolaryngology, Head & Neck Operative Surgery https://vula.uct.ac.za/access/content/group/ba5fb1bd-be95-48e5-81be-586fbaeba29d/Cricothyroidotomy%20and%20needle%20cricothyrotomy.pdf
3. Open Access Atlas of Otolaryngology, Head & Neck Operative Surgery https://vula.uct.ac.za/access/content/group/ba5fb1bd-be95-48e5-81be-586fbaeba29d/Percutaneous%20dilational%20tracheostomy%20surgical%20technique.pdf%20

Chapter 6

MECHANICAL VENTILATION

✓ Objectives

- Discuss the indications and techniques for noninvasive positive pressure ventilation.
- Describe the clinical parameters that should be reviewed to decide whether the patient is failing to respond to noninvasive methods and requires invasive mechanical ventilation.
- Describe the characteristics of different types of breaths and modes of mechanical ventilation.
- Outline ventilator settings and monitoring needs for the initiation of mechanical ventilation.
- Describe interactions between ventilatory parameters and modifications needed to avoid harmful effects of mechanical ventilation.
- Review the guidelines for initial ventilator management that apply to specific clinical situations.

Case Study

A 67-year-old woman with severe chronic obstructive pulmonary disease presents to the hospital and reports an upper respiratory tract illness and increasing shortness of breath of 2 days' duration. She has been using her home nebulizers without relief. Her vital signs show a blood pressure of 140/90 mm Hg, heart rate of 122 beats/min, respirations of 32 breaths/min, and a temperature of 37.2°C (99.0°F). Physical examination is remarkable for use of accessory muscles of respiration and diffuse wheezing bilaterally. She is alert but unable to speak in full sentences. An arterial blood gas analysis demonstrates a pH of 7.49, PCO_2 of 29 mm Hg, and a PO_2 of 48 mm Hg. Bronchodilator therapy is started, and the woman is given IV steroids.

- What type of respiratory support should be initiated?
- What settings should be selected for respiratory support?
- What are the goals of respiratory support?

I. INTRODUCTION

When hypoxic or hypercapnic respiratory failure cannot be treated by other means, advanced support with positive pressure ventilation may be needed. A ventilator is a device used to assist or replace the work of the respiratory system. Positive pressure ventilation can be delivered noninvasively via a mask or helmet or invasively via an endotracheal tube or tracheostomy. Generally accepted indications for initiating positive pressure ventilatory support are summarized in **Table 6-1**.

Table 6-1 Indications for Positive Pressure Ventilatory Support

Ventilation abnormalities	Respiratory muscle dysfunction • Respiratory muscle fatigue • Chest wall abnormalities • Neuromuscular disease
	Decreased ventilatory drive
	Increased airway resistance and/or obstruction
Oxygenation abnormalities	Refractory hypoxemia
	Need for positive end-expiratory pressure
Work of breathing alterations	Need for decreased work of breathing • Shock • Respiratory muscle fatigue • Severe acidosis
Need for sedation and/or neuromuscular blockade	
Need to decrease systemic or myocardial oxygen consumption	
Use of hyperventilation to reduce intracranial pressure (in cases of imminent herniation)	
Facilitation of alveolar recruitment and prevention of atelectasis	

II. NONINVASIVE POSITIVE PRESSURE VENTILATION

A. What Is Noninvasive Positive Pressure Ventilation?

Noninvasive positive pressure ventilation (NPPV) refers to a form of mechanical ventilation that provides respiratory assistance without an invasive artificial airway. The potential beneficial effects of NPPV are similar to those of invasive mechanical ventilation and include decreased work of breathing, improved oxygenation, and improved gas exchange. In addition, this type of ventilation avoids many of the complications associated with intubation and invasive mechanical ventilation. Potential advantages and disadvantages of NPPV are listed in **Table 6-2**.

Table 6-2 Advantages and Disadvantages of Noninvasive Positive Pressure

[redacted] Ventilation

Advantages	Disadvantages
Reduced need for sedation	Claustrophobia
Preservation of airway-protective reflexes	Increased workload for respiratory practitioner
Avoidance of upper airway trauma	Facial/nasal pressure lesions
Decreased incidence of nosocomial sinusitis and pneumonia	Unprotected airway
Improved patient comfort	Inability to suction deep airway
Shorter length of stay in ICU and hospital	Gastric distension with use of face mask or helmet
Improved survival	Possible upper extremity edema, axillary vein thrombosis, tympanic membrane dysfunction, and intrahelmet noise with use of helmet
	Delay in intubation

B. How Does NPPV Work?

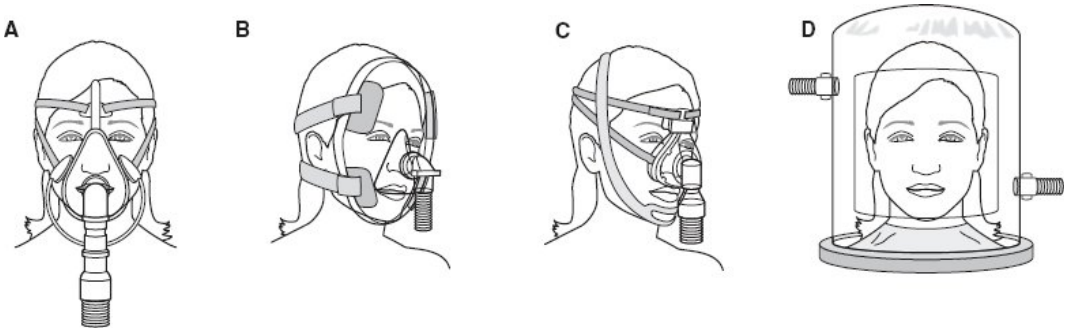
NPPV uses two levels of positive airway pressure, combining the modalities of pressure support ventilation (PSV) and continuous positive airway pressure (CPAP) (discussed later). By convention, the PSV modality is referred to as IPAP (inspiratory positive airway pressure), and the CPAP modality is referred to as EPAP (expiratory positive airway pressure). CPAP alone can also be delivered noninvasively but does not provide support of ventilation. CPAP allows spontaneous breathing from a gas source at an elevated baseline system pressure (higher than atmospheric pressure) and is functionally equivalent to positive end-expiratory pressure (PEEP). The difference between these two pressure levels (ΔP) determines tidal volume generated. NPPV can be delivered using a standard ICU ventilator or a portable device. The benefits of using an ICU ventilator include delivery of a more precise and higher concentration of oxygen, the separation of inspiratory and expiratory tubing to prevent rebreathing CO_2, better monitoring and alarm features, and improved detection of air leaks. Alarm setups may need to be altered on standard ventilators because the alarms are typically triggered by exhalation, and noninvasive ventilation inherently has more gas leakage compared with ventilation via an endotracheal tube. Ventilators specifically designed to provide patient-triggered noninvasive pressure support or patient-triggered volume-cycled breaths are optimal.

C. What Types of Interfaces Are Available?

The ventilator connects to a tightly fitted face mask, nasal mask, nasal plugs, or a helmet (**Figure 6-1**). Many patients with acute respiratory failure are mouth breathers, so the face mask is preferred because it is associated with smaller leaks than the nasal plugs and nasal mask. The nasal passages may offer significant resistance to airflow, limiting the benefits of NPPV. Some gas leakage is anticipated with both masks and can be compensated for by increasing pressure settings or increasing the set tidal volume (VT) level. When a nasal mask is used, the patient's mouth should be kept closed or chin straps should be employed to reduce leakage.

The use of the helmet as an interface for the NPPV device has been increasing recently. The levels of PEEP that can be delivered through the helmet can be higher than those that can be obtained with other interfaces or with a high-flow nasal cannula. Benefits of the helmet include comfort, where the patient can move more freely, or the ability to partially preserve some intake, like drinking through a straw if needed. In addition, less skin injury and lacerations are noted. Assessing the tidal volume is usually difficult when using a helmet because of varying distention. Disadvantages could include noise, accumulation of CO_2 in the helmet, and desynchrony between the patient and the ventilator because of less sensitivity of triggering.

Figure 6-1. Devices for Delivery of Noninvasive Positive Pressure Ventilation



Examples of noninvasive positive pressure ventilation delivery devices: **A**, face mask; **B**, total face mask; **C**, nasal mask with chin strap; and **D**, helmet.

D. Which Patients Benefit From NPPV?

Before NPPV is initiated, patient characteristics and the potential for successfully treating the underlying respiratory condition should be evaluated. **Table 6-3** lists conditions leading to respiratory failure that are likely to improve with use of NPPV. Of these, acute exacerbations of chronic obstructive pulmonary disease and cardiogenic pulmonary edema are the two conditions best studied and they have accepted indications for the application of NPPV. An approach to initiating NPPV after appropriate patient evaluation is outlined in **Table 6-4**. NPPV is best used in the alert, cooperative patient whose respiratory condition is expected to improve in 24 to 48 hours. Potential candidates should be hemodynamically stable, able to control airway secretions, and able to synchronize with the ventilator. If a provider skilled in the application of NPPV is not available, if the patient is too sick for this support, or if NPPV has failed to benefit the patient, it is critical to move quickly to invasive mechanical ventilation.

Table 6-3 Respiratory Conditions Likely to Respond to Noninvasive Positive Pressure Ventilation

Hypoxemic Respiratory Failure

- Cardiogenic pulmonary edema without hemodynamic instability
- Respiratory failure in patients with mild to moderate *Pneumocystis* pneumonia
- Respiratory failure in immunocompromised patients (especially in hematologic malignancies and transplant patients)
- Respiratory failure of likely reversible cause within 48–72 hours

Hypercapnic Respiratory Failure

- Acute exacerbation of chronic obstructive pulmonary disease
- Acute exacerbation of asthma
- Respiratory failure in patients with cystic fibrosis

Table 6-4 Initiation of Noninvasive Positive Pressure Ventilation

- Do not delay intubation if needed and keep in mind the patient's resuscitation status.
- Consider ABG analysis prior to initiation.
- Explain the procedure.
- Keep head of bed at ≥45°.
- Ensure appropriate mask or helmet size.
- Assess the patient's tolerance of the mask by applying it by hand before securing the harness.
- Use the following initial ventilator settings:
  - Mode: Spontaneous
  - Trigger: Maximum sensitivity
  - FIO_2: 1.00
  - EPAP: 4–5 cm H_2O (higher levels are poorly tolerated initially)
  - IPAP: 10–15 cm H_2O
  - Backup rate: Start at 6/min
- Adjust the difference between EPAP and IPAP to achieve an effective V_T and CO_2 clearance. Adjust EPAP for alveolar recruitment in increments of 2 cm H_2O per step to improve oxygenation. Depending on the ventilator, a similar increase in IPAP may be required to maintain the same V_T. The V_T will be identified on the NPPV machine with each breath the patient takes.
- If assist-control volume ventilation is used, begin with a V_T of 6 to 8 mL/kg (depending on the underlying pulmonary condition).
- Titrate pressures, volume, and FIO_2 to achieve appropriate pH, PaO_2, and $PaCO_2$ levels. Ventilator changes can be made every 15 to 30 minutes.
- Follow vital signs, pulse oximetry, mental status, clinical appearance, and ABG (if indicated).
- Remember that goals of NPPV may include a respiratory rate <30 breaths/min, V_T 6-8 mL/kg of predicted body weight, improved gas exchange, and patient comfort.
- It is also important to be cognizant that IPAP >20 cm H_2O may lead to gastric distension.

Abbreviations: ABG, arterial blood gas; EPAP, expiratory positive airway pressure; IPAP, inspiratory positive airway pressure; NPPV, noninvasive positive pressure ventilation; VT, tidal volume

E. Which Patients Should Not Receive Noninvasive Mechanical Ventilation?

In general, NPPV should not be initiated in the following circumstances: uncooperative patients; patients with difficulty clearing secretions, recurrent emesis, or post-cardiac or respiratory arrest; and patients with hemodynamic instability. A more detailed list of contraindications for the use of NPPV is presented in **Table 6-5**.

Table 6-5 Contraindications to Use of Noninvasive Positive Pressure Ventilation

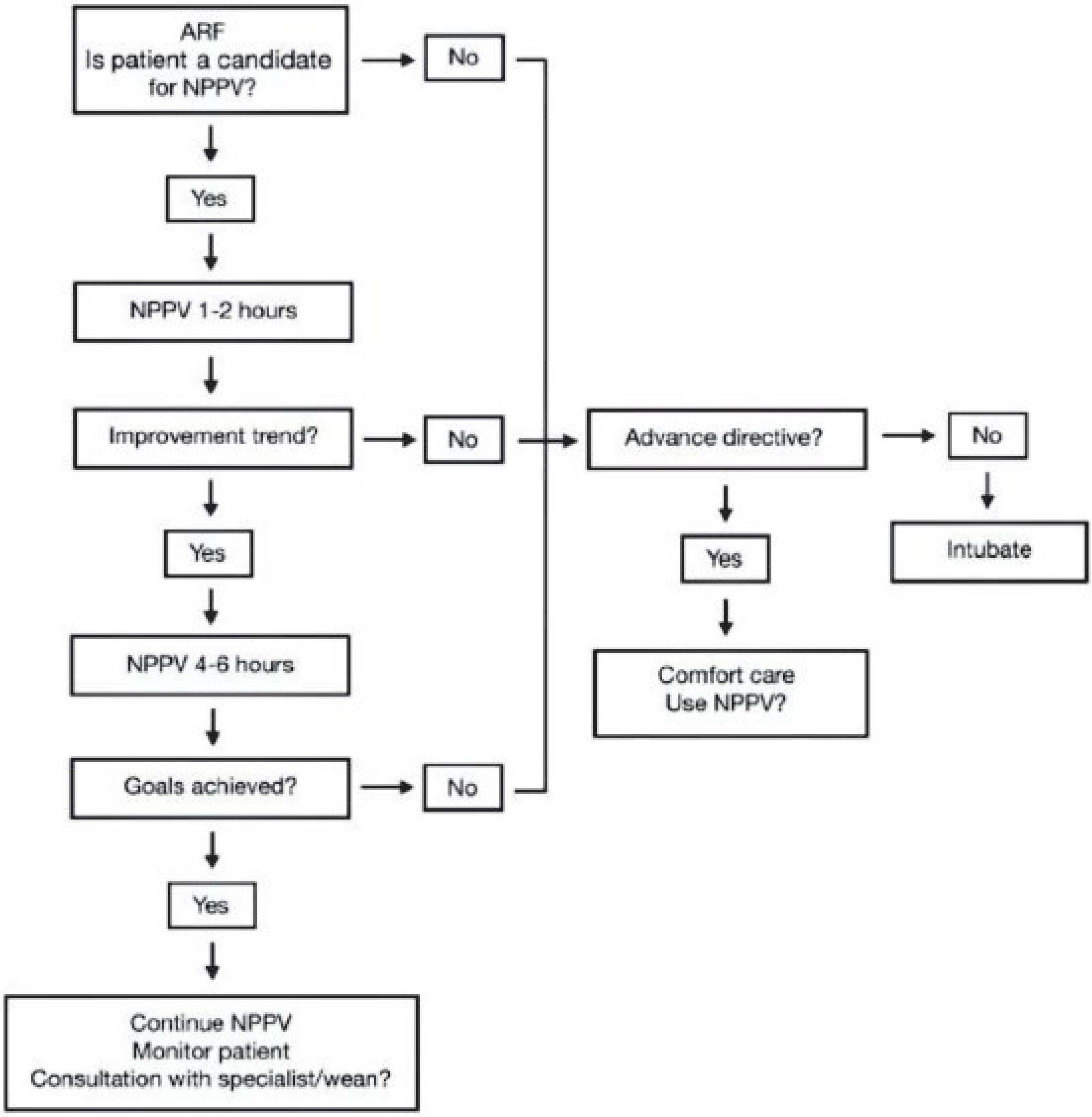
- Cardiac or respiratory arrest
- Hemodynamic instability
- Myocardial ischemia or arrhythmias
- Patient who is unable to cooperate
- Inability to protect the airway
- High risk for aspiration
- Active upper gastrointestinal hemorrhage
- Severe hypoxemia
- Severe encephalopathy
- Facial trauma/recent facial surgery and/or burns
- Significant agitation

F. How Are Patients Monitored on NPPV?

Avoid inspiratory pressures greater than 20 cm H_2O *because gastric distension can occur.*

Patients receiving NPPV must be monitored closely in a proper setting, and continuous pulse oximetry and cardiac monitoring are suggested. Close clinical follow-up assessments are required, including evaluations of the pH, PaO_2, and $PaCO_2$. Consider transition to invasive ventilation when a clear trend toward improvement has not been observed over the first 1 or 2 hours, or when the therapeutic goals have not been achieved within the first 4 to 6 hours. Sedation should be used cautiously and with adequate monitoring when NPPV is initiated. Additional measures that may be considered include application of a protective nose and mouth patch to protect any pressure injuries and gastric decompression if a face mask or helmet is used. Oral intake should be restricted until the patient has stabilized and intubation is no longer a consideration. An algorithm for assessing NPPV is presented in **Figure 6-2**.

Figure 6-2. Assessment of Noninvasive Positive Pressure Ventilation



ARF
Is patient a candidate for NPPV?
No
Yes
NPPV 1-2 hours
Improvement trend?
No
Advance directive?
No
Intubate
Yes
Comfort care
Use NPPV?
Yes
NPPV 4-6 hours
Goals achieved?
No
Yes
Continue NPPV
Monitor patient
Consultation with specialist/wean?

Abbreviations: ARF, acute respiratory failure; NPPV, noninvasive positive pressure ventilation

Case Study (continued)

Noninvasive positive pressure ventilation is initiated. Two hours after initiation, the patient exhibits persistent marked accessory muscle use and altered mental status. Vitals signs now show a heart rate of 130 beats/min, blood pressure of 160/90 mm Hg, respiratory rate of 32 breaths/min, and temperature of 36.6°C (98°F). Arterial blood gas demonstrates a pH of 7.27, PCO_2 of 60 mm Hg, and PO_2 of 90 mm Hg. Patient is now somnolent.

- Should this patient be intubated and invasive mechanical ventilation initiated?
- What are the initial settings on invasive mechanical ventilation?
- How should patients on invasive mechanical ventilation be monitored?

III. DECISION TO INTUBATE

The decision to initiate invasive mechanical ventilation is a crucial and time-sensitive one. Delay in intubation, inability to identify a difficult airway, and inability to anticipate possible hemodynamic consequences of intubation can reduce the likelihood of good patient outcomes. In general, consideration of three quick bedside questions can help facilitate a prompt decision to proceed with invasive mechanical ventilation, especially when transitioning from noninvasive ventilation.

- Is there failure in airway maintenance or protection (eg, inability to handle secretions)?
- Is there failure to achieve desired goals with current respiratory support (oxygenation, ventilation, or work of breathing)?
- Is the illness anticipated to worsen in the next 24 to 48 hours?

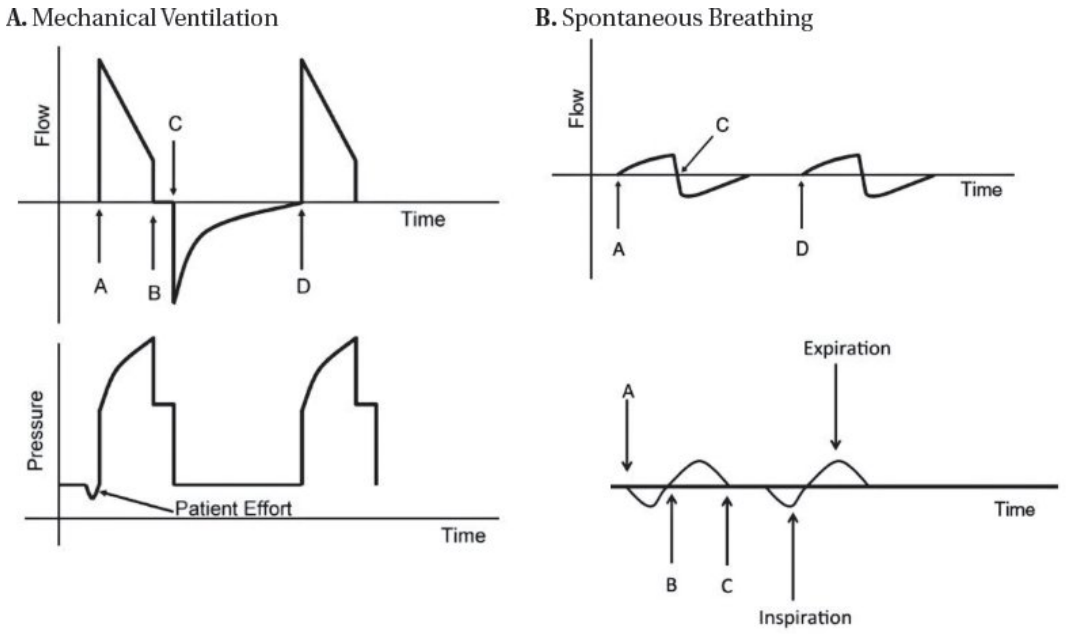
IV. INVASIVE MECHANICAL VENTILATION

Mechanical ventilation via an endotracheal tube is commonly used to support critically ill patients. It is a definitive intervention with the goal of obtaining acceptable oxygenation and ventilation with a secure airway.

Each mechanical ventilation respiratory cycle can be divided into two phases: inspiration and expiration (**Figure 6-3A**).

The respiratory cycle is the time from the initiation of one breath until the initiation of the next breath. Triggering (A) signals the transition from expiration to inspiration; cycling (C) indicates the transition from inspiration to expiration. Other components of the total respiratory cycle (ABCD) include inspiratory pause (BC), inspiration (ABC), and expiration (CD). Spontaneous breaths do not include an inspiratory pause. The spontaneous respiratory cycle (ACD) is demonstrated in **Figure 6-3B**.

Figure 6-3. Respiratory Cycle During Mechanical Ventilation and Spontaneous Breathing



Triggering (A) signals the transition from expiration to inspiration; (B) end inspiratory flow; cycling (C) indicates the transition from inspiration to expiration. Total respiratory cycle (**ABCD**), inspiration (**ABC**), and expiration (**CD**).

Start of inspiration (A), start of expiration (B), inspiration (**AB**), expiration (**BC**), and total respiratory cycle (**ABC**)

Inspiration is the point at which the exhalation valve closes and fresh gas under pressure from the ventilator enters the chest. The amount of gas delivered during inspiration is determined by any of three targets that can be set on the ventilator: volume, pressure, and/or flow.

Cycling is the changeover from the end of inspiration to the expiratory phase. It occurs in response to one of three parameters: elapsed time, delivered volume, or a decrease in flow rate. During expiration, the ventilator gas flow is stopped, and the exhalation circuit is opened to allow gas to escape passively from the lungs. Expiration continues until the next inspiration begins.

Triggering is the changeover from expiration to inspiration. Triggering a ventilator-delivered breath depends on the patient's interaction with the ventilator:

- *Assisted breath*: The patient initiates a breath, and this inspiratory effort produces a drop in airway pressures or a diversion of constant gas flow in the ventilator circuitry. A signal triggers the ventilator to deliver a breath. This is an example of partial ventilator control.
- *Unassisted, mandatory, or controlled breath*: In the absence of patient interaction with the ventilator, breaths are delivered based on elapsed time (eg, at a set rate of 10 breaths/min and no detection of patient effort, the ventilator will be triggered every 6 seconds). This is an example of full ventilator control.

Spontaneous breaths (no ventilator assistance) are also possible in synchronized intermittent mandatory ventilation (SIMV) and bilevel ventilation. The most common ventilator breaths are described later. CPAP allows spontaneous breathing at a higher baseline pressure.

V. TYPES OF TARGETED/CYCLED BREATHS

A. Volume-Cycled Breath

A volume-cycled breath, often called *volume assist-control breath*, ensures the delivery of a preset tidal volume (unless the peak pressure limit is exceeded). On most ventilators, the setting of peak inspiratory flow rate and the choice of inspiratory flow waveform (square, sine, or decelerating) determine the length of inspiration. Some ventilators change the peak inspiratory flow rate to maintain constant inspiratory time on switching between a constant flow (square) and decelerating flow (ramp) waveforms. With volume-cycled breaths, worsening airway resistance or lung/chest-wall compliance results in increases in peak inspiratory pressure to maintain the set tidal volume (unless the peak pressure limit is exceeded and the ventilator will discontinue the remainder of the breath to avoid excessively high inspiratory pressures).

B. Time-Cycled Breath

A time-cycled breath, often called *pressure assist-control breath*, applies a constant pressure for a preset time. The application of pressure throughout inspiration results in a square (constant) pressure-over-time waveform during inspiration and a decelerating inspiratory flow waveform as the pressure gradient falls between the ventilator and the patient (since pressure rises as the lung fills). Flow in this breath format is variable and this leads to variable tidal volume depending on lung compliance. Flow depends on the resistance of the lung, the compliance of the lung, and patient effort. With this type of breath, changes in airway resistance or lung/chest-wall compliance will alter tidal volume (ie, worsening of airway resistance or lung compliance results in a decrease in tidal volume).

C. Flow-Cycled Breath

A flow-cycled breath, usually called a *pressure support breath*, is a spontaneous mode of ventilation. The patient initiates every breath and the ventilator delivers support with the preset pressure value. With this support, the patient self-regulates the respiratory rate and tidal volume. The set inspiratory pressure support level is kept constant with a decelerating flow.

The patient triggers all breaths. A change in the mechanical properties of the lung/thorax and/or patient effort affects the delivered tidal volume. The pressure support level must be regulated to obtain the desired ventilation.

Pressure support breaths are terminated when the flow rate decreases to a predetermined percentage of the initial peak flow rate (typically 25%). As the patient's inspiratory effort decreases, the flow decreases, marking the proximity of the end of inspiration.

VI. MODES OF MECHANICAL VENTILATION

The mode of ventilation describes how one or more types of ventilator breaths interface with the patient to provide ventilatory support. When mechanical ventilation is initiated, the optimum ventilatory support for a given clinical circumstance and the specific needs of the patient must be determined. Commonly used modes of ventilation include assist-control (AC) ventilation, SIMV, and PSV. The various modes are achieved by using some combination of the three types of ventilator breaths and may be combined with the application of PEEP.

A. Assist-Control Ventilation

AC ventilation can be delivered with either volume-cycled (volume assist-control) or time-cycled (pressure assist-control) breaths. We will emphasize volume control because it is the most commonly used mode.

In volume AC, the preset VT is guaranteed at a preset flow rate and with a set minimum respiratory rate. The patient can initiate breaths and trigger the ventilator, and the ventilator will assist to achieve the preset VT delivered at the preset flow. Thus, patients receive the minimum number of ventilator breaths (set rate), but the total number of breaths is higher if the patient triggers the ventilator with additional inspiratory efforts.

With proper use of AC, the work of breathing may be significantly decreased. However, if the ventilator and the patient are not in synchrony or if the ventilator inspiratory flow rates are not matched to the patient's demand, this mode may result in an increase in the patient's work of breathing.

The total number of breaths during AC ventilation may be higher than the minimum set rate, based on the patient's respiratory drive and ability to trigger the ventilator. This mode has also been called continuous mandatory ventilation (CMV). However, CMV more accurately represents a situation in which the patient does not trigger additional breaths (ie, absent respiratory drive, as when the patient is paralyzed [discussed next]).

The other breath type of AC is pressure control. Pressure and inspiration time are set, allowing the breath to be delivered at a certain rate per minute. In pressure control, the set pressure is the controlling parameter and time is the signal that ends the inspiration. The delivered tidal volume is determined by these set parameters and the compliance of the lungs. The flow is determined by the set pressure, the inspiratory:expiratory ratio (I:E ratio), lung resistance and compliance, and the patient's efforts. As the patient's compliance decreases or resistance increases, the tidal volume will decrease. If compliance increases or resistance decreases, then tidal volume will increase.

B. Pressure Support Ventilation

PSV provides a preset level of inspiratory pressure assist with each ventilator-detected patient effort. This inspiratory assist is selected to overcome the increased work of breathing imposed by the disease process, endotracheal tube, inspiratory valves, and other mechanical aspects of ventilatory support. The set amount of pressure that is applied augments each patient-triggered breath. All breaths are flow cycled (usually, the assist will decelerate when flow falls $< 25\%$ of the initial flow rate generated by the patient-initiated breath). The patient controls the respiratory rate and exerts a strong influence on the duration of inspiration, flow rate, and VT. In addition, the delivered VT is influenced by pulmonary compliance and resistance. Rapid changes in these parameters potentially alter the VT and work of breathing. PSV may be coupled with SIMV (see next section), primarily as a means to diminish excess work of breathing for spontaneous breaths occurring between mandatory breaths.

!

PSV augments the patient's own respiratory effort and is best adjusted by observing changes in the patient's respiratory rate, VT, and comfort.

!

The amount of pressure support is titrated according to the patient's VT measured by the ventilator during expiration. Suggested parameters include a setting that achieves one or more of the following goals:

- A VT of 6 to 8 mL/kg, depending on patient needs
- A slowing of spontaneous breathing rate to an acceptable range (< 30 breaths/min)
- The desired minute ventilation

Appropriate apnea alarms and a backup ventilation setting are essential. Potential benefits of PSV include the comfort and tolerance this ventilatory mode offers some patients. In addition, PSV may reduce the work of breathing by diminishing patient-ventilator asynchrony. Typically, as pressure support is increased in patients with lung disease, the patient's work of breathing and respiratory rate decrease and VT increases. With PSV, an endotracheal tube cuff leak may interfere with appropriate cycling because flow may never drop to the preset threshold for cycling (ie, 25% of the peak flow rate).

C. Synchronized Intermittent Mandatory Ventilation

SIMV delivers either volume-cycled or time-cycled breaths at a preset mandatory rate. Volume cycling is most commonly used for the mandatory breaths. This type of ventilation may not be suited for the critically ill patient who requires a set VT to be delivered with every breath and are fully dependent on the ventilator support. Breaths may be triggered by the patient or by the time elapsed. If the patient-initiated breath falls within a certain period of time before the onset of the mandatory breath, the ventilator synchronizes its support by delivering the mandatory breath early, thus essentially converting a controlled breath to an assisted one. The number of breaths that will be synchronized in this fashion is the preset (mandatory) rate. When no effort is detected, the ventilator delivers the preset VT at the preset (time-elapsed) rate. When the patient initiates breaths over the set mandatory rate spontaneously, these breaths are usually supported by the ventilator (assisted breaths) with the addition of pressure support. Notice the difference from assist control—volume control ventilation, in which each breath (patient- or ventilator-initiated) had the same guaranteed VT.

!

It is recommended that PSV be used in conjunction with SIMV to decrease the patient's work of breathing during spontaneous breaths.

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In SIMV, the addition of pressure support to these spontaneous patient-initiated breaths is recommended, using a value that offsets the resistance of the endotracheal tube. Synchronization allows for enhanced patient-ventilator synchrony by delivering the preset machine breaths in conjunction with the patient's inspiratory effort for each mandatory breath.

The SIMV mode allows patients to contribute to and determine a portion of their ventilatory requirement. The negative inspiratory pressure generated by spontaneous breathing may lead to increased venous return to the right side of the heart, which may improve cardiac output and cardiovascular function. When no pressure support is added, potential increases in work of breathing may delay weaning from mechanical ventilation.

D. Controlled Mechanical Ventilation

!

Do not confuse the CMV (assist-control) setting on modern ventilators for controlled mechanical ventilations.

!

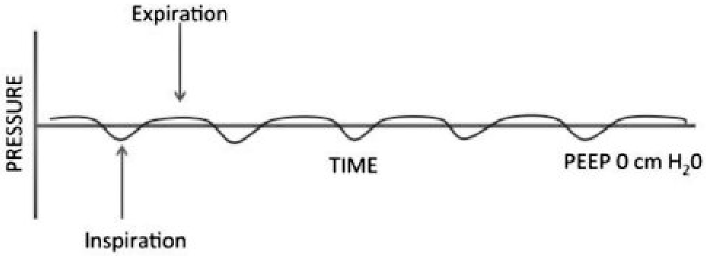
CMV delivers unassisted ventilator breaths at a preset rate. All breaths are mandatory and are either volume-cycled or time-cycled. No additional spontaneous assisted breaths are initiated beyond the set number of controlled breaths. Current ventilators do not allow direct setting of CMV, and this mode can be achieved only in patients who are not capable of spontaneous respiratory effort, such as those who are heavily sedated or receiving neuromuscular blockade during surgery under anesthesia.

E. CPAP and Weaning

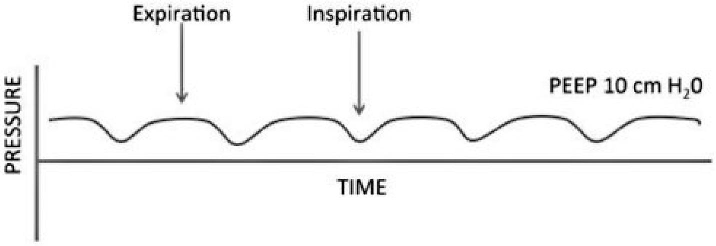
CPAP is seldom used as initial support for acute respiratory failure in a patient who is intubated and is not considered a mode of mechanical ventilation. Here continuous positive pressure is applied throughout the respiratory cycle with the patient breathing spontaneously around the applied pressure. Therefore, respiratory rate and VT depend entirely on the patient's inspiratory effort (without help from the ventilator) as the patient inspires against the resistance of the endotracheal tube. CPAP with low levels of pressure support (typically 5–7 cm of water) may be used for weaning during the final stages of invasive ventilation when patients are being assessed for their potential readiness for extubation.

Airway pressure and flow tracings of spontaneous respiration, CPAP, and the different modes of mechanical ventilation are illustrated in **Figure 6-4**.

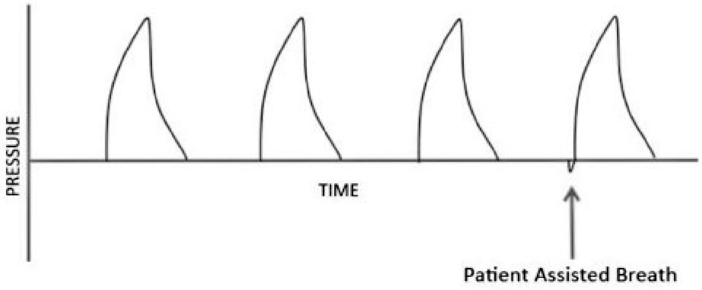
Figure 6-4. Airway Pressure and Flow Tracings


Expiration
PRESSURE
TIME
PEEP 0 cm H20
Inspiration

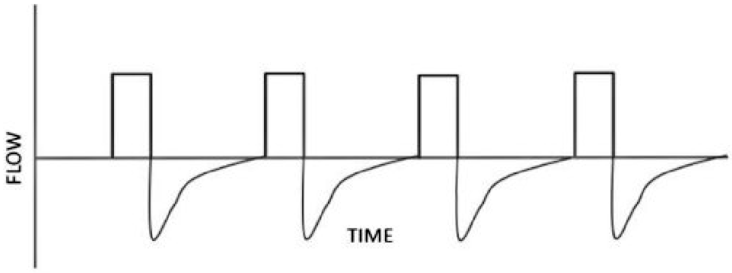
A. Spontaneous Breathing


Expiration
Inspiration
PEEP 10 cm H20
PRESSURE
TIME

B. Continuous Positive Airway Pressure

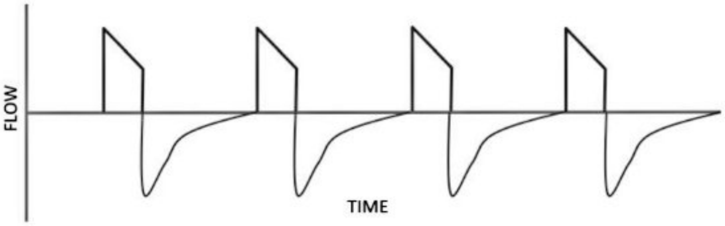

PRESSURE
TIME
Patient Assisted Breath

C. Volume Assist Control – Pressure Time Waveform

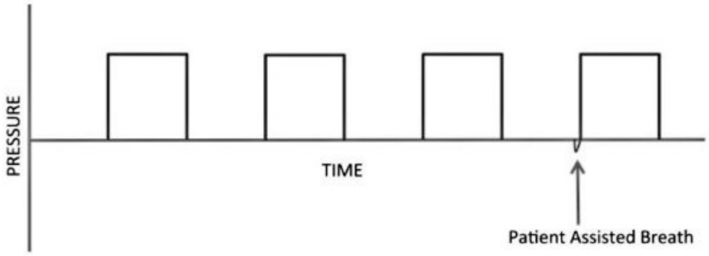


D. Volume Assist Control – Flow Time Waveform
(Square Constant Flow)

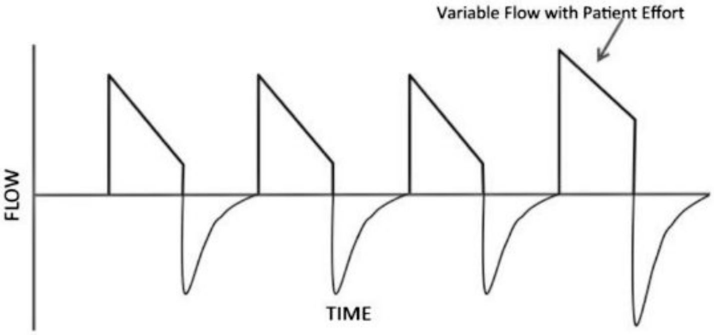
E. Volume Assist Control – Flow Time Waveform
(Decelerating Constant Flow)



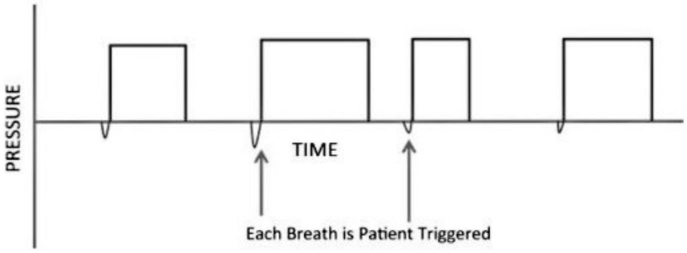
F. Pressure Assist Control Ventilation – Pressure Time Waveform



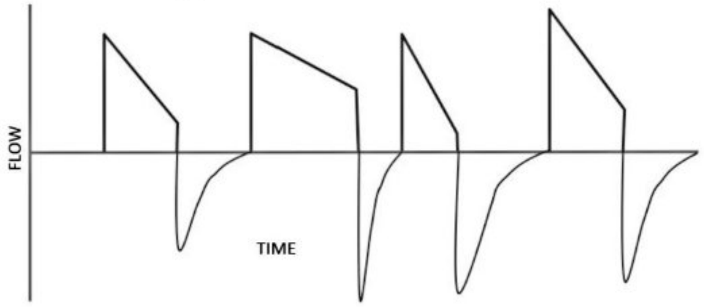
G. Pressure Assist Control Ventilation – Flow Time Waveform



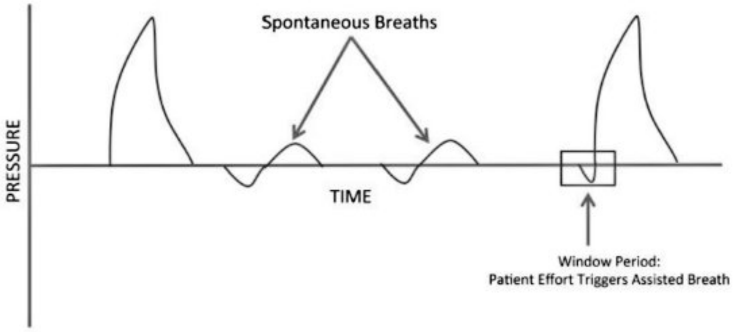
H. Pressure Support Ventilation – Pressure Time Waveform



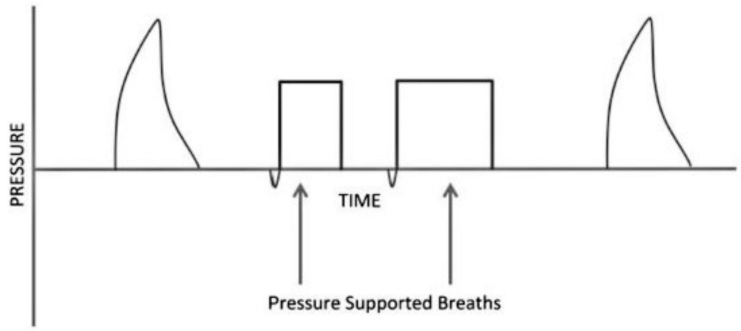
I. Pressure Support Ventilation – Flow Time Waveform



J. SIMV without Pressure Support – Pressure Time Waveform


Spontaneous Breaths
PRESSURE
TIME
Window Period:
Patient Effort Triggers Assisted Breath

K. SIMV with Pressure Support – Pressure Time Waveform


PRESSURE
TIME
Pressure Supported Breaths

The advantages and disadvantages of the various modes of invasive mechanical ventilation are summarized in **Table 6-6**. In choosing a mode of ventilation, it is important to consider specific goals, the most important of which are adequacy of ventilation and oxygenation, reduction in the work of breathing, and the assurance of patient comfort and synchrony with the ventilator.

Table 6-6	Potential Advantages and Disadvantages of Selected Modes of

[redacted] Mechanical Ventilation

Mode	Advantages	Disadvantages
AC volume ventilation	• Reduced work of breathing • Ensures minimum minute ventilation • Comfortable respiratory pattern	• Excessive inspiratory pressures • Barotrauma • Auto-PEEP • Respiratory alkalosis
AC pressure ventilation	• Variable flow rates • Limits pressure	• Variable V_T
Pressure support ventilation	• Patient comfort • improved patient-ventilator interaction • Decreased work of breathing • Augmented patient breaths • Flow-cycled breaths	• Apnea alarm may not trigger backup ventilation mode • ET cuff leak can affect cycling • Requires spontaneous breathing
Synchronized intermittent mandatory ventilation	• Volume or time-cycled breaths • Patient or time-elapsed initiation of breaths • Improved preload with negative pressure spontaneous respirations	• Increased work of breathing compared with AC • Not a good mode for critically ill patients • Increased WOB if pressure support not set to assist spontaneous breaths
Controlled mechanical ventilation	• Rests muscles of respiration completely • Volume or time-cycled only	• Requires use of sedation/neuromuscular blockade • Adverse hemodynamic effects • Patient is unable to trigger any spontaneous breaths

Abbreviations: AC, assist-control; ET, endotracheal; VT, tidal volume; WOB, work of breathing

VII. CHOOSING A MODE AND INITIAL VENTILATOR SETTINGS

Choosing a mode of mechanical ventilation depends on the reason it is required and the underlying disease process. In general, AC is used as the initial mode for a patient needing invasive mechanical ventilation.

When initiating ventilatory support in adults, a fraction of inspired oxygen (FIO_2) of 1.0 is used to ensure maximal amount of available oxygen during the patient's adjustment to the ventilator and during the initial attempts to stabilize the patient's condition. In addition, the high level of oxygen offers support for complications that may have occurred before and during intubation. The usual recommended VT level is 6 to 8 mL/kg of the predicted body weight. Higher VT levels should be avoided to reduce the possibility of lung injury. An appropriate respiratory rate should be set to achieve the desired minute ventilation. Normal minute ventilation (VT × respiratory rate) is approximately 7 to 8 L/min, but certain conditions may require levels that more than double this baseline. Minute ventilation should be adjusted to produce the $PaCO_2$ level that allows an acceptable acid-base (pH) status for the patient's clinical condition. As a general rule, FIO_2, mean airway pressure, and PEEP affect the PaO_2, whereas the respiratory rate, dead space (VD), and VT affect alveolar minute ventilation and $PaCO_2$.

To estimate predicted body weight

- *Males:*
  50 + 2.3 (height in inches – 60)
  50 + 0.91 (height in cm – 152.4)
- *Females:*
  45.5 + 2.3 (height in inches – 60)
  45.5 + 0.91 (height in cm – 152.4)

Although a normal or close to normal pH status may allow resumption of optimal functioning of the cellular metabolism essential to the recovery of a critically ill patient, in some circumstances (acute respiratory distress syndrome and severe obstructive lung disease), the goals of mechanical ventilation are not to normalize blood gases. Hypercapnia and respiratory acidosis are tolerated in such situations to achieve goals such as minimizing dynamic hyperinflation and avoiding ventilator-associated lung injury. Hence, individual ventilator settings and their titration contribute to a dynamic process that must be tailored to the patient's changing needs. Guidelines for the initiation of mechanical ventilation are listed in **Table 6-7**.

Table 6-7 Guidelines for the Initiation of Mechanical Ventilation

1. Choose the ventilator mode with which you are most familiar. The primary goals of ventilatory support are adequate oxygenation/ventilation, reduced work of breathing, synchrony between patient and ventilator, and avoidance of high end-inspiration alveolar pressures.
2. The initial FIO_2 should be 1.0. The FIO_2 thereafter can be titrated downward to maintain the SpO_2 at 92% to 94%. In ARDS, SpO_2 ≥88% may be acceptable to minimize complications of mechanical ventilation.
3. Initial V_T = 6 to 8 mL/kg in patients with relatively normal lung compliance. In patients with poor lung compliance (eg, ARDS), a target V_T of 4 to 6 mL/kg by PBW is recommended to avoid overdistension and maintain an inspiratory plateau pressure ≤30 cm H_2O.
4. Choose a respiratory rate and minute ventilation appropriate for the particular clinical requirements. Target pH, not $PaCO_2$.
5. Use PEEP in diffuse lung injury to maintain an open alveoli at end expiration. If volume is held constant, PEEP may increase peak inspiratory plateau pressure, a potentially undesirable effect in ARDS. PEEP levels >15 cm H_2O are rarely necessary.
6. Set the trigger sensitivity to allow minimal patient effort to initiate inspiration. Beware of auto cycling if the trigger setting is too sensitive.
7. In patients at risk of obstructive airway disease, avoid choosing ventilator settings that limit expiratory time and cause or worsen auto-PEEP.
8. Call the critical care consultant or other appropriate consultant for assistance.

Abbreviations: ARDS, acute respiratory distress syndrome; PBW, predicted body weight; PEEP, positive end-expiratory pressure; SpO_2, oxyhemoglobin saturation as measured by pulse oximetry; VT, tidal volume

VIII. CONTINUING CARE DURING MECHANICAL VENTILATION

After mechanical ventilation has been initiated, the following parameters should be assessed and titrated to achieve the desired goals. Many important interrelationships exist among ventilator settings, and the consequences of making any change must be appreciated. This interdependency of parameters may lead to beneficial or harmful effects in the respiratory and/or cardiovascular systems. Critical care consultation should be obtained for continuing ventilator management.

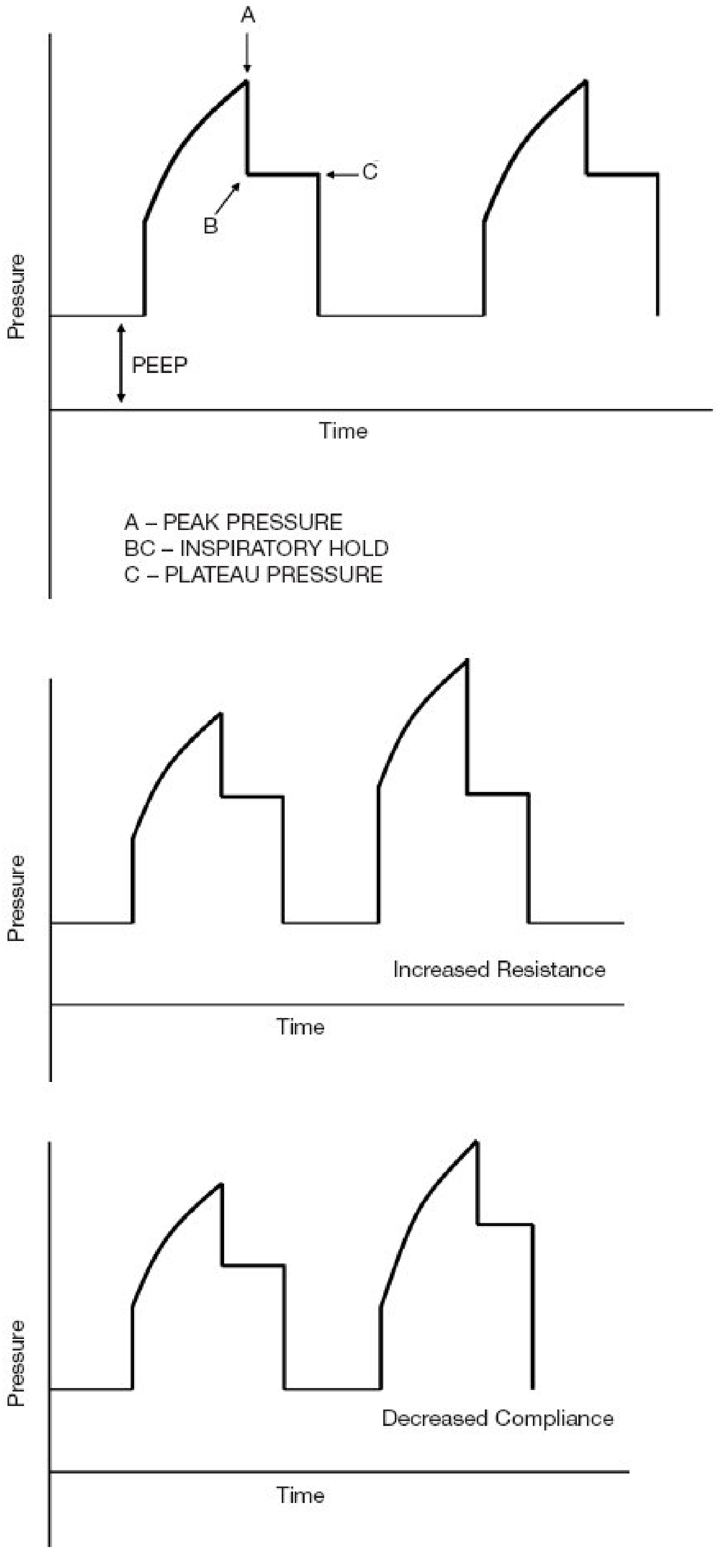
A. Inspiratory Pressures

During positive pressure volume assist-control ventilation, airway pressure rises progressively to a peak inspiratory pressure (Ppeak; **Figure 6-5**), which is reached at end inspiration. The Ppeak is the sum of the pressure required to overcome airway resistance and the pressure required to overcome the elastic properties of the lung and chest wall. Ppeak, sometimes referred to as *peak airway pressure*, is affected by many other variables, such as the flow rate, diameter of the endotracheal tube, secretions, and diminished bronchial diameter. When an inspiratory hold is applied at the end of inspiration, gas flow ceases, all dynamic factors are eliminated, and the pressure drops to a measurement called the *inspiratory plateau pressure* (Pplat). The Pplat reflects the pressure required to overcome the elastic recoil within the lung and chest wall and, contrary to the Ppeak, is a static pressure. The Pplat is the best estimate of peak alveolar pressure, which is an important indicator of alveolar distension. Accurate measurement of Pplat requires the absence of any patient effort and an inspiratory hold for a minimum of 0.5 seconds (usually 1 second).

Potential adverse effects from high inspiratory pressures include barotrauma, volutrauma, and reduced cardiac output. Barotrauma (pneumothorax, pneumomediastinum) and volutrauma (lung parenchymal injury caused by overinflation), although linked to high Ppeak, correlate best with Pplat. The relation of Ppeak and Pplat is illustrated in **Figure 6-5**. This figure demonstrates airway pressure tracings for typical volume assist-control ventilation under conditions of normal compliance and resistance, increased airway resistance, and decreased respiratory system compliance.

As mentioned earlier, an example of the relationship of Ppeak and Pplat to alveolar distension is demonstrated by the effect of endotracheal tube size on Ppeak and Pplat. As the internal diameter of an endotracheal tube is decreased in a patient receiving (fixed volume) ventilation, the same VT will result in higher Ppeak, yet Pplat (obtained during inspiratory hold) and alveolar distension remain unchanged as the pressure is dissipated across the resistance of the endotracheal tube. The same VT, regardless of the type of breath, produces the same alveolar distension at end inspiration. To avoid injury in patients receiving mechanical ventilation, Pplat should be maintained < 30 cm H_2O. When compliance is decreased, both Ppeak and Pplat rise for a fixed VT. As resistance is unchanged, the difference between peak pressure and plateau pressure is not affected.

Figure 6-5. Relationship of Peak Inspiratory Pressure and Inspiratory Plateau Pressure


A
C
B
Pressure
PEEP
Time
A – PEAK PRESSURE
BC – INSPIRATORY HOLD
C – PLATEAU PRESSURE
Pressure
Increased Resistance
Time
Pressure
Decreased Compliance
Time

Abbreviation: PEEP, positive end-expiratory pressure

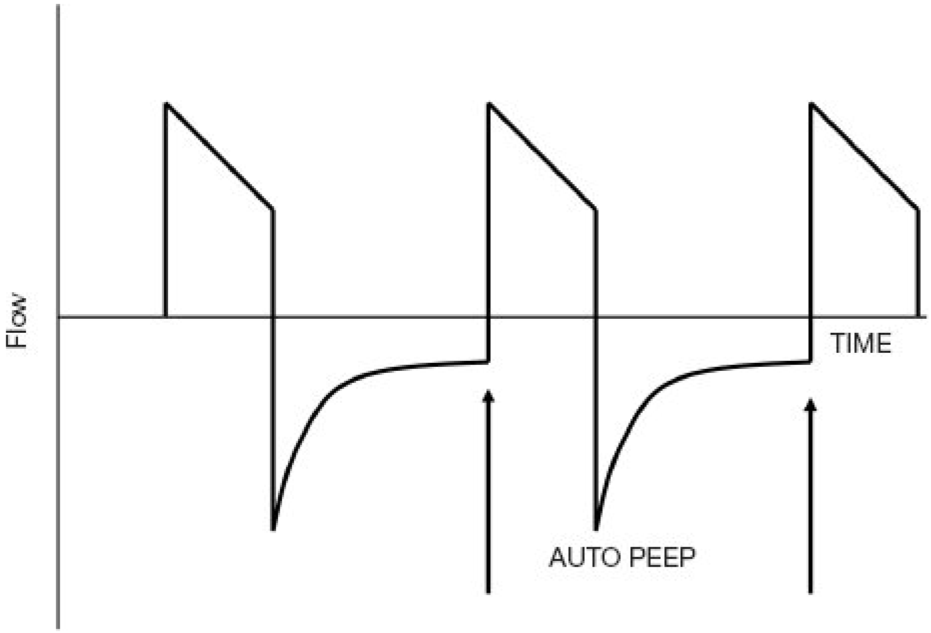
Elevated Pplat may be reduced by the following interventions:

- Decrease PEEP, which may also decrease oxygenation and worsen alveolar collapse (if PEEP is used to improve oxygenation and alveolar stability).
- Decrease VT, which may lead to hypercapnia because of a reduction in minute ventilation.
- Avoid and decrease auto-PEEP (see next section) with interventions that prolong the expiratory time, understanding that this may lead to hypercapnia.

B. Relation of Inspiratory Time to Expiratory Time and Auto-PEEP

If the expiratory time is too short to allow full exhalation, the previously delivered breath is not completely expired and the next lung inflation is superimposed on the residual gas in the lung. This results in lung hyperinflation and PEEP above the preset level on the ventilator. This increase in end-expiratory pressure is called *auto-PEEP*, or *intrinsic, inadvertent, or occult PEEP*. Auto-PEEP can be quantified by using manual methods or through electronic programs within some ventilators during an expiratory hold maneuver. However, it is most easily diagnosed qualitatively by viewing the flow-versus-time graphic waveform tracing available on most mechanical ventilators because the expiratory flow fails to reach the zero flow level before the initiation of the next breath (**Figure 6-6**). The potentially harmful physiologic effects of auto-PEEP on peak, plateau, and mean airway pressures are the same as those of preset PEEP. In addition, high levels of PEEP may decrease venous return to the heart, resulting in hypotension and higher PCO_2 because of increased dead space, and adversely affect oxygenation (especially with asymmetric lung disease).

Figure 6-6. Flow-Time Waveform Demonstrating Auto-PEEP



Abbreviation: PEEP, positive end-expiratory pressure

Auto-PEEP may be reduced by the following interventions:

- Decrease respiratory rate by changing the set rate or sedating the patient. These interventions result in fewer inspirations per minute and thus increase the total expiratory time available; this is the most effective way of decreasing auto-PEEP.
- Decrease VT, which requires less time to deliver a smaller breath and allows more time for exhalation.
- Increase flow rate, delivering the VT faster and allowing more time in the cycle for exhalation. This intervention has little impact unless the initial flow rate was set at an extremely low level. It will also lead to an increase in the airway pressure.
- Change the inspiratory waveform from decelerating (ramp) to constant (square), which delivers VTin a shorter time, allowing

more time for exhalation.

As discussed previously, the first two interventions may lead to hypercapnia because of a reduction in minute ventilation; however, the benefits of a decrease in auto-PEEP despite the lower minute ventilation may lead to little change in $PaCO_2$. When severe air trapping occurs, allowing sufficient expiratory time may improve ventilation and CO_2 removal. Hypercapnia and a controlled reduction in pH (permissive hypercapnia) may be acceptable in some clinical conditions but requires expert consultation. This approach may not be suitable for patients with intracranial hypertension because hypercapnia causes cerebral vasodilation and further increases in the intracranial pressure.

C. FIO_2

High levels of inspired oxygen may be harmful to lung parenchyma after prolonged exposure. Although the precise threshold for concern is not known, it is desirable to reduce the FIO_2 to ≤ 0.5 (50% oxygen) within the first 24 hours. However, hypoxemia is always considered a greater risk to the patient than high FIO_2 levels. The primary determinants of oxygenation during mechanical ventilation are FIO_2 and mean airway pressure. Other minor determinants include VT, inspiratory-expiratory ratio, inspiratory flow rate, PEEP, auto-PEEP, use of inspiratory pause, and the inspiratory flow waveform pattern (volume breaths). In the patient with acute respiratory distress syndrome (ARDS), PEEP becomes a major determinant of mean airway pressure. The interrelationships of these various parameters, as already demonstrated, often lead to complex adjustments within the mechanical ventilation plan.

D. Minute Ventilation and Alveolar Minute Ventilation

Minute ventilation, defined as the amount of gas exchanged by an individual in 1 minute, is calculated as the respiratory rate multiplied by mean VT. The primary determinant of CO_2 exchange during mechanical ventilation is the alveolar minute ventilation, calculated as:

$$VA = (VT - VD)f$$

in which VD is dead space and f is the respiratory rate. The VT, the respiratory rate, and their interrelationships with other ventilatory parameters have already been discussed. Physiologic VD represents, in general, lung units that are relatively well ventilated but under-perfused. The physiologic effect of high amounts of VD is hypercapnia (impaired CO_2 clearance). Dead space may result from the pathologic process in the lung or from mechanical ventilation complicated by high airway pressures, low intravascular volume, or low cardiac output.

As previously discussed, adequate ventilation is assessed by consideration of both the $PaCO_2$ and the pH. Hyperventilation resulting in a low $PaCO_2$ level may be an appropriate short-term compensatory goal during metabolic acidosis while the primary etiology is corrected. Similarly, a patient with chronic hypercapnia has an increased baseline $PaCO_2$ and maintains a near-normal pH by renal compensation (increased bicarbonate retention). Patients with chronic compensated hypercapnia should receive sufficient minute ventilation during mechanical ventilation to maintain the $PaCO_2$ at their usual (baseline) level, and utmost attention should be paid to the pH to avoid severe alkalemia and loss of retained bicarbonate.

E. Humidification

Gases delivered by mechanical ventilators are typically dry, and the upper respiratory tract is bypassed by artificial airways, resulting in loss of heat and moisture. Heating and humidification of gases are routinely provided during mechanical ventilation to prevent mucosal damage and minimize inspissation of secretions. Available systems include passive humidifiers (artificial nose) or active, microprocessor-controlled heat and humidifying systems (heated humidifiers). The passive humidifiers are contraindicated in the presence of copious secretions, minute ventilation > 12 L/min, air leaks > 15% of delivered tidal volume, or blood in the airway.

F. Use of Positive End-Expiratory Pressure

Adjustment of PEEP is the cornerstone strategy employed for disease states that cause alveolar collapse or airway closure (eg, ARDS). It causes alveolar recruitment and prevents repeated opening and closing of the alveoli (atelectrauma). Titration of PEEP for hypoxemic respiratory failure secondary to ARDS can be performed according to the PEEP/FIO_2 combinations given in **Table 6-8**.

Table 6-8 Suggested Combinations of PEEP and FIO_2 to Reach Goal PaO_2

Fio_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7
PEEP (cm H_2O)	5–14	5–14	8–16	8–16	10–20	10–20	10–20	12–20	14–20
FIO2	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	
PEEP (cm H_2O)	14–22	14–22	14–22	16–22	18–22	20–22	22	24	

Abbreviations: PEEP, positive end-expiratory pressure; FIO_2, fraction of inspired oxygen

In patients with severe obstructive lung disease, applying external PEEP and setting it close to the auto-PEEP value can help offset the work of breathing to trigger the ventilator. Seeking expert consultation is prudent if higher levels of PEEP are required to maintain oxygenation.

G. Prophylactic Therapies

Mechanical intubation is a risk factor for venous thromboembolism, gastric stress ulceration, and nosocomial pneumonia. Measures to prevent venous thromboembolism include the prophylactic use of anticoagulation (unless contraindicated) and/or pneumatic compression devices. Using a proton pump inhibitor or histamine 2-receptor blocker is warranted for stress ulcer prevention. The risk of ventilator-associated pneumonia (ventilator bundle) is reduced by elevation of the head of the bed to ≥ 30°, oral hygiene, and daily evaluations for liberation from mechanical ventilation.

IX. SEDATION, ANALGESIA, AND NEUROMUSCULAR BLOCKADE

Endotracheal intubation and mechanical ventilation can be uncomfortable and anxiety provoking. To improve the patient's comfort and synchrony with the ventilator, anxiolytics, sedatives, and analgesics may be administered. Neuromuscular blocking agents should be used with caution, and expert consultation should be sought before initiation. Guidelines for the use of these agents are outlined in the Society of Critical Care Medicine's *Clinical Practice Guidelines for Sustained Neuromuscular Blockade in the Adult Critically Ill Patient* and in *Clinical Practice Guidelines for the Management of Pain, Agitation, and Delirium in Adult Patients in the Intensive Care Unit*. Caution also should be exercised with use of sedation in nonintubated patients with acute respiratory insufficiency or impending respiratory failure.

X. VENTILATORY GUIDELINES FOR SPECIFIC CLINICAL SITUATIONS

Case Study

A previously healthy 36-year-old man presents to the hospital and reports a cough, sputum production, and a fever of 2 days' duration. An admission chest radiograph reveals a developing infiltrate in the left lower lobe. The man is admitted to the general ward and started on antibiotics for community-acquired pneumonia. Less than 24 hours later, the patient continues to deteriorate and requires oxygen at 10 L/min. He is not in obvious respiratory distress; however, pulse oximetry reveals severe hypoxemia (83% to 89% on supplemental oxygen, 10 L/min). Sputum cultures show *Streptococcus pyogenes* (group A) colonies, and a new chest radiograph reveals new, diffuse bilateral alveolar infiltrates. The patient is intubated because of worsening hypoxemia.

- What initial ventilator settings would you use for this patient?
- What steps should be taken to minimize barotrauma during ventilation?
- What parameters should be measured and monitored?

A. Acute Respiratory Distress Syndrome

ARDS causes a decrease in lung compliance, making the lungs stiff and difficult to inflate, and produces hypoxemic respiratory failure. Guidelines for mechanical ventilation in ARDS are outlined in **Tables 6-8** and **6-9**. High Ppeak and Pplat complicate mechanical ventilation because of the low lung compliance or high airway resistance. Lower VT_2 (4–6 mL/kg of predicted body weight) is required, and the Pplat should be maintained at the desired level of ≤ 30 cm H_2O; permissive hypercapnia may be required to accomplish that goal. The FIO_2 is increased as necessary to prevent hypoxemia but reduced as soon as other ventilatory interventions are effective. Because of increased shunt in ARDS, hypoxemia may be severe. PEEP is the most effective way to improve oxygenation and is typically applied in the range of 8 to 15 cm H_2O, based on the severity of hypoxemia. Higher PEEP levels may be indicated in severe lung injury. Although patients with ARDS are somewhat less likely to develop auto-PEEP because expiratory time requirements are reduced as a result of decreased lung compliance (stiffness), its presence should be monitored, especially at higher inspiratory-expiratory ratios. **Table 6-9** outlines the recommended strategy for ventilating patients with ARDS. **Table 6-8** outlines the recommended FIO_2 and PEEP combinations.

Table 6-9 Mechanical Ventilation in Acute Respiratory Distress Syndrome

Goals

- Pa_{O_2}: 55–80 mm Hg (7.3–10.7 kPa)
- Pplat: ≤30 cm H_2O
- VT: 4–6 mL/kg PBW
- pH: >7.15 is acceptable

Start with Assist-Control with VT of 8 mL/kg PBW

- Decrease by 1 mL/kg over the next 4 hours until VT of 4–6 mL/kg is reached.
- If Pplat is >30 cm H_2O, decrease VT by 1 mL/kg until VT is 4 mL/kg or arterial pH reaches 7.15.
- If using VT of 4 mL/kg and Pplat is <25 H_2O, VT can be increased by 1 mL/kg until Pplat is 25 cm H_2O or VT is 6 mL/kg.
- If a Pplat of ≤30 cm H_2O has been achieved with a VT >6 mL/kg and a lower VT is clinically problematic (ie, need for increased sedation), it is acceptable to maintain the higher VT.

Initiation of PEEP in Acute Respiratory Distress Syndrome

- Initiate PEEP at 5 cm H_2O and titrate up in increments of 2–3 cm H_2O (**Table 6-8**).
- Full recruitment effect may not be apparent for several hours.
- Monitor blood pressure, heart rate, and Pa_{O_2} or pulse oximetry during PEEP titration and at intervals while the patient is receiving PEEP therapy.
- Optimal PEEP settings are typically 8–15 cm H_2O.

NOTE: These guidelines are summarized to facilitate early intervention in critical patients. The physician should be familiar with these situations and seek appropriate consultation as soon as possible.

Abbreviations: PBW, predicted body weight; PEEP, positive end-expiratory pressure; Pplat, plateau pressure; VT, tidal volume

Case Study

A 28-year-old woman with a history of asthma is intubated and admitted to the ICU for an acute asthma exacerbation. Peak airway pressure on admission was 40 cm H_2O, and Pplat was 25 cm H_2O immediately after intubation; however, 6 hours later, peak airway pressures have arisen to 55 cm H_2O while the Pplat has remained the same.

- What is the likely etiology of her high peak airway pressures in the setting of unchanged plateau pressures?
- What adjunctive therapies, in addition to ventilator support, does this patient need to reduce the elevated airway pressures?
- Which parameter (ie, peak airway pressure or Pplat) has been associated with a higher risk of barotrauma in an intubated patient?

B. Obstructive Airway Disease

Mechanical ventilation for patients with asthma and chronic obstructive pulmonary disease is designed to support oxygenation and assist ventilation until airway obstruction has improved. After initial intubation, airway secretions and persistent small airway obstruction may manifest as elevated peak airway pressures and a normal Pplat. This suggests an airway obstruction (not worsening compliance), and bronchodilators and steroids should be used aggressively to help alleviate this obstruction while mechanical ventilation supports the patient. As airflow improves, the patient will tolerate higher VT levels and longer inspiratory times.

Mechanical ventilation in these patients may also produce hyperinflation, auto-PEEP, and resultant hypotension. Therefore, careful attention is needed to balance cycle, inspiratory, and expiratory times. The initial VT should be 6 to 8 mL/kg, and the minute ventilation should be adjusted to a low normal pH. With volume ventilation, the inspiratory flow rate should be set to optimize the inspiratory-expiratory ratio and allow complete exhalation. Such management reduces breath stacking and the potential for auto-PEEP.

C. Asymmetric Lung Disease

Asymmetric lung disease or injury that occurs after aspiration, contusion, or a localized pneumonia may cause abnormal distribution of ventilation and gas exchange during mechanical ventilation. Because the conditioned gas from the ventilator follows the path of least resistance along the bronchi, the VT is distributed primarily to the less-affected (more-compliant) lung and may overexpand it. Overdistension of the less-affected lung and poor expansion of the diseased/injured lung worsen ventilation-perfusion relationships in both lungs, and hypoxemia and hypercapnia may occur, persist, or worsen, in addition to causing injury to the normal lung. Standard settings and principles of ventilator support should be initiated. However, if this is unsuccessful, expert consultation should be obtained to facilitate further efforts at patient management. Putting the less-involved lung in the gravitationally dependent (decubitus) position may be helpful in directing pulmonary blood flow to lung units receiving better ventilation. Other techniques, such as differential lung ventilation, could be considered, and immediate expert consultation may be required.

D. Heart Disease

The major goals of ventilatory support in patients with myocardial ischemia are to decrease the work of breathing and ensure adequate oxygen delivery to the heart. Decreasing the work of breathing will reduce the consumption of oxygen by respiratory muscles, thus increasing oxygen availability to the heart. Patients with cardiogenic pulmonary edema who are mechanically ventilated receive additional benefit from the decrease in preload as a result of increased intrathoracic pressure. Left ventricular afterload also decreases through application of positive juxtacardiac pressure during systole.

E. Neuromuscular Disease

Patients with peripheral neuromuscular disease typically have an intact respiratory drive and normal lungs. These patients may require a higher VT level to avoid the sensation of dyspnea. Adjustments are made in other ventilatory parameters to ensure a normal arterial pH.

XI. MONITORING MECHANICAL VENTILATORY SUPPORT

Patients who receive mechanical ventilatory support require continuous monitoring to assess the beneficial and potential adverse effects of treatment (**Table 6-10**). Arterial blood gas measurements provide valuable information about the adequacy of oxygenation, ventilation, and acid-base balance. This information is essential during the initial phases of ventilatory support and during periods of patient instability. If available, a pulse oximeter and end-tidal capnometer (for measuring end-tidal CO_2) can be used to further monitor the patient’s progress.

Table 6-10 Recommendations for Monitoring Mechanical Ventilatory Support

- Obtain a chest radiograph after intubation and repeat as indicated to evaluate any deterioration in status.
- Obtain arterial blood gas measurements after initiation of mechanical ventilation and intermittently based on patient status.
- Measure vital signs frequently and observe the patient directly (including patient-ventilator interaction).
- Measure inspiratory plateau pressure as clinically appropriate.
- Use pulse oximetry to monitor oxygenation.
- Use ventilator alarms to monitor key physiologic and ventilator parameters.

Ventilators are equipped with sophisticated alarms and monitors to assist with patient management and detection of adverse events. When initiating ventilatory support, the respiratory care practitioner usually establishes alarm parameters for low and high minute ventilation, high inspiratory pressures, and low exhaled volumes and pressures. Many ventilators allow for the measurement of auto-PEEP.

The low-pressure alarm is intended to alert the clinician to a leak in the circuit or to ventilator disconnection. A high-pressure alarm warns that the set maximum peak airway pressure has been exceeded; this alarm is usually set 10 cm H_2O above the patient's baseline peak airway pressure. If a patient receiving volume ventilation develops mucous plugging or a marked change in airway resistance or lung compliance, the peak pressure will rise acutely. If the peak pressure alarm sounds with volume ventilation, it implies that the patient is not receiving the set VT because inspiration ends when the pressure alarm limit is exceeded. Conversely, in pressure preset modes of ventilation, changes in airway resistance or lung compliance will trigger the low exhaled volume alarm.

XII. HYPOTENSION ASSOCIATED WITH INITIATION OF MECHANICAL VENTILATION

A. Tension Pneumothorax

When hypotension occurs immediately after initiation of mechanical ventilation, tension pneumothorax should be one of the first considerations. This diagnosis is based on a physical examination that finds decreased or absent breath sounds and tympany to percussion on the side of the pneumothorax. Tracheal deviation away from the side of the pneumothorax may be observed, although it is uncommon after placement of an endotracheal tube. Treatment includes emergent decompression by inserting a large-bore catheter or needle into the second or third intercostal space in the midclavicular line. Treatment should not be delayed awaiting a chest radiograph. The insertion of a catheter or needle is both diagnostic and therapeutic: it improves blood pressure and reverses the findings of physical examination. The insertion of the catheter or needle must be followed by chest tube placement.

B. Conversion from Negative to Positive Intrathoracic Pressure

Normal intrathoracic pressure is slightly negative relative to the atmosphere. When positive pressure ventilation is initiated, intrathoracic pressure becomes positive. As intrathoracic pressure rises, right atrial pressure rises and the intravascular pressure gradient for return of blood from the large extrathoracic veins into the right heart decreases. As a result, blood return to the heart may be reduced. Left ventricular preload, stroke volume, cardiac output, and blood pressure then may decrease in sequence. Underlying intravascular volume depletion exacerbates the deleterious effects of the increased intrathoracic pressure on cardiac output and blood pressure. Treatment of this common complication includes volume resuscitation by means of rapidly infused fluid boluses to raise extrathoracic venous pressure and increase venous return to the right heart until the blood pressure increases. Oxygen saturation should be monitored to avoid overly aggressive fluid resuscitation. Use of ventilation techniques associated with high mean airway pressure may exacerbate the deleterious hemodynamic consequences of mechanical ventilation.

C. Auto-PEEP

As previously discussed, auto-PEEP occurs when the combination of ventilator settings and patient physiology results in an inadequate expiratory time. Excessive end-expiratory pressure may increase intrathoracic pressure and cause hypotension because of decreased venous return to the heart.

Although auto-PEEP may occur in any patient, those with obstructive airway disease are particularly predisposed to this condition because of the need for a prolonged expiratory phase.

D. Acute Myocardial Ischemia/Infarction

Stress from the cause of acute respiratory failure, as well as the stress of intubation itself, may lead to increased myocardial oxygen demand and to acute myocardial ischemia, infarction, and subsequent hypotension. Patients at high risk should be evaluated with serial electrocardiograms and myocardial markers of injury.

XIII. READINESS AND WEANING FROM INVASIVE MECHANICAL VENTILATION

Mechanical ventilation is not without complications, including and not limited to, superimposed infections, laryngeal injury, diaphragmatic dysfunction, and others.

The need to assess the readiness of a patient to wean from mechanical ventilation should be done on a daily basis and those patients that can be freed from mechanical ventilation should be disconnected from the machines as soon as possible without risking complications.

A few clinical parameters and criteria can be used as indicators for readiness to wean. Below are some criteria used:

- The main cause of the respiratory failure that lead to the intubation and mechanical ventilation has improved significantly or resolved.
- Adequate mental status to maintain an airway (including the ability to clear secretions)
- Adequate oxygen saturation $> 90\%$, $PO_2 > 60$ mm Hg with FIO_2 40–50%

- PEEP around 5–8 cm H_2O
- pH $>$ 7.25
- Able to initiate inspiratory effort
- Appropriate mentation to protect airway
- Minimal secretions with strong cough
- Hemodynamically stable and no escalation of resuscitation or vasopressors

Weaning patients from mechanical ventilation to extubation can be a challenging process. Formal discontinuation assessment should be done when the patient is placed on a spontaneous breathing trial (SBT), and not receiving significant support from the machine. The SBT should continue for about 30 minutes, and no more than 2 hours. There are few predictors and parameters that should be examined and achieved before the decision is made to extubate the patient. The use of Negative Inspiratory Force (NIF), Force Vital Capacity (FVC), or the Respiratory Shallow Breathing Index (RSBI) have been used by many clinicians. Expert consultation should be considered when deciding to extubate the patient.

As many as one in every five patients with planned extubation might require re-intubation. This failure is highly dependent on the correct evaluation of previously described parameters. Most extubation failures occur within the first 24 hours up to 72 hours after extubation.

Key Points

Mechanical Ventilation

- The primary goals of noninvasive and invasive positive pressure ventilation are to support ventilation and oxygenation, and to reduce work of breathing while ensuring patient comfort.

- NPPV is best used in the alert, cooperative patient whose respiratory condition is expected to improve in 24 to 48 hours.
- The advantages and disadvantages of the different modes of invasive mechanical ventilation must be considered when determining the optimal ventilatory support for the patient's clinical condition.
- Guidelines for initiating mechanical ventilation should be carefully followed, with adjustments made based on patient assessment and monitoring.
- The complex interactions of inspiratory pressures, inspiratory-expiratory ratio, FIO_2, and PEEP must be appreciated to evaluate the potential benefits and harmful effects in each patient.
- The primary determinants of oxygenation are FIO_2 and mean airway pressure, whereas alveolar ventilation primarily affects CO_2 exchange.
- During mechanical ventilation, a patient must be closely monitored using the ventilator alarm systems, continuous pulse oximetry, attentive physical assessment, measurement of inspiratory Pplat (as clinically appropriate), and intermittent arterial blood gases and chest radiographs as needed.
- High inspiratory plateau pressures are associated with a higher incidence of ventilator-induced lung injury and should be maintained below 30 cm H_2O.
- Hypotension occurring immediately after initiation of invasive mechanical ventilation should prompt evaluation for tension pneumothorax, decreased venous blood return because of intrathoracic pressure, auto-PEEP, or myocardial ischemia.

Suggested Readings

1. Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med*. 2000;342:1301-1308.
2. Caples SM, Gay PC. Noninvasive positive pressure ventilation in the intensive care unit: a concise review. *Crit Care Med*. 2005;33:2651-2658.
3. Fink M, Abraham E, Vincent J, et al, eds. Chapter 66: Controlled mechanical ventilation. In: *Textbook of Critical Care*. 5th ed. Philadelphia, PA: WB Saunders Co; 2005.
4. Fink M, Abraham E, Vincent J, et al, eds. Chapter 67: Patient-ventilator interaction. In: *Textbook of Critical Care*. 5th ed. Philadelphia, PA: WB Saunders Co; 2005.
5. Hess DR, Kacmarek RM. *Essentials of Mechanical Ventilation*. 2nd ed. New York, NY: McGraw-Hill Companies; 2002.
6. Kallet RH, Jasmer RM, Pittet JF, et al. Clinical implementation of the ARDS Network protocol is associated with reduced hospital mortality compared with historical controls. *Crit Care Med*. 2005;33:925-929.
7. Leisching T, Kwok H, Hill NS. Acute applications of noninvasive positive pressure ventilation. *Chest*. 2003;124:699-713.
8. MacIntyre N. Ventilatory management of ALI/ARDS. *Semin Respir Crit Care Med*. 2006;27:396-403.
9. MacIntyre N, Branson RD. *Mechanical Ventilation*. Philadelphia, PA: WB Saunders Co; 2000.
10. MacIntyre NR, Cook DJ, Ely EW Jr, et al. Evidence-based guidelines for weaning and discontinuing ventilatory support: a collective task force facilitated by the American College of Chest Physicians; the American Association for Respiratory Care; and

the American College of Critical Care Medicine. *Chest*. 2001;120(6 Suppl):375S.

11. Marini JJ. Dynamic hyperinflation and auto-PEEP end-expiratory pressure: lessons learned over 30 years. *Am J Respir Crit Care Med*. 2011;184:756-762.
12. Marini JJ, Gattinoni L. Ventilatory management of acute respiratory distress syndrome: a consensus of two. *Crit Care Med*. 2004;32:250-255.
13. Murray MJ, Cowen J, DeBlock H, et al. Clinical practice guidelines for sustained neuromuscular blockade in the adult critically ill patient. *Crit Care Med*. 2002;30:142-156.
14. Petrucci N, Iacovelli W. Ventilation with smaller tidal volumes: a quantitative systematic review of randomized controlled trials. *Anesth Analg*. 2004;99:193-200.
15. Tobin MJ. Advances in mechanical ventilation. *N Engl J Med*. 2001;344:1986-1996.
16. Tobin MJ. *Principles and Practice of Mechanical Ventilation*. 3rd ed. McGraw Hill Companies; 2013.

Suggested Website

1. Society of Critical Care Medicine/Guidelines. www.SCCM.org.

Chapter 7

MONITORING OXYGEN BALANCE AND ACID-BASE STATUS

Objectives

- Outline the determinants of oxygen balance.
- Recognize disorders of oxygen delivery.
- Assess oxygen balance.
- Discuss hemodynamic monitoring and volume responsiveness.
- Explain the use of acid-base status in monitoring the seriously ill patient.
- Discuss acid-base disturbances.
- Describe disease processes that cause metabolic acidosis.

Case Study

A 67-year-old woman with a medical history of hypertension, diabetes mellitus, and systolic heart failure (left ventricular ejection fraction [LVEF 20%]) presented to the hospital with altered mental status and shortness of breath. The patient's pulse is 123 beats/min, blood pressure 84/54 mm Hg, respiratory rate 28 breaths/min, and oxygen saturation on pulse oximetry (SpO_2) 89% while breathing room air. She was found to have a lower gastrointestinal bleed.

- What monitoring devices should be implemented?
- What blood tests should be obtained to determine whether the oxygen balance is adequate?

I. INTRODUCTION

Monitoring devices are not therapeutic and information from monitoring devices must be integrated with patient assessment and clinical judgment to determine optimal care. In addition, the clinician must be aware of the limitations and risk-benefit ratio of a monitoring system. Monitoring may be as simple as measuring the pulse or temperature or as complex as invasive hemodynamic techniques with direct and calculated measurements. Physiologic stress leads to early effects on the heart rate, respiratory rate, vascular tone, and blood pressure. Significant abnormalities of these vital signs may suggest the need for more intensive monitoring. More invasive monitoring strategies carry a higher risk of complications, but should be considered if they provide sufficient new information to guide therapy. This chapter will emphasize only basic monitoring techniques that can be initiated in most care environments.

The goals of monitoring in seriously ill patients are to recognize physiologic abnormalities and to guide interventions. These actions help to ensure adequate blood flow and oxygen delivery for maintenance of cellular and organ function. Tissue oxygenation cannot be directly measured or monitored at the bedside in a predictable and reliable manner. However, estimates of the adequacy of oxygenation can be made based on knowledge of the oxygen balance, which is determined by oxygen delivery and oxygen consumption. An understanding of these principles is required to appreciate the usefulness and limitations of various monitoring tools.

II. PRINCIPLES OF OXYGEN DELIVERY

Organs consume oxygen to make energy and therefore organs require oxygen to function properly. In addition, oxygen delivery requires the driving force of the cardiovascular system. Oxygen delivery is defined as the amount of oxygen presented to the tissues. Oxygen consumption is defined as the amount of oxygen needed to meet the body's metabolic demands. At baseline, the body delivers 4–5 times more oxygen than what is needed by the tissues. This extra delivery is the oxygen reservoir that is available for sharp increases in consumption, such as running away from a threat (**Figure 7-1**). In critical illness, physiologic derangements that result in an absolute decrease in the oxygen delivered or an increase in tissue oxygen demand may compromise this margin of safety. In addition, adequate oxygen delivery does not always guarantee appropriate oxygen utilization. For example, infection leading to sepsis can decrease the mitochondria's ability to effectively use oxygen at the tissue level. Efforts to improve oxygen delivery are more easily manipulated in the critically ill patient than oxygen consumption. Oxygen delivery is dependent on the oxygen content of arterial blood and the ability of the body to carry it to the tissues (cardiac output).

$$\text{Oxygen delivery } (DO_2) = \text{cardiac output (CO)} \times \text{arterial oxygen content } (CaO_2)$$

Invasive and/or more complex noninvasive monitoring is required for exact measurement of cardiac output. However, an understanding of the variables that determine oxygen content in the blood and cardiac output, along with less invasive monitoring, may guide appropriate treatment.

A. Oxygen Content of Arterial Blood

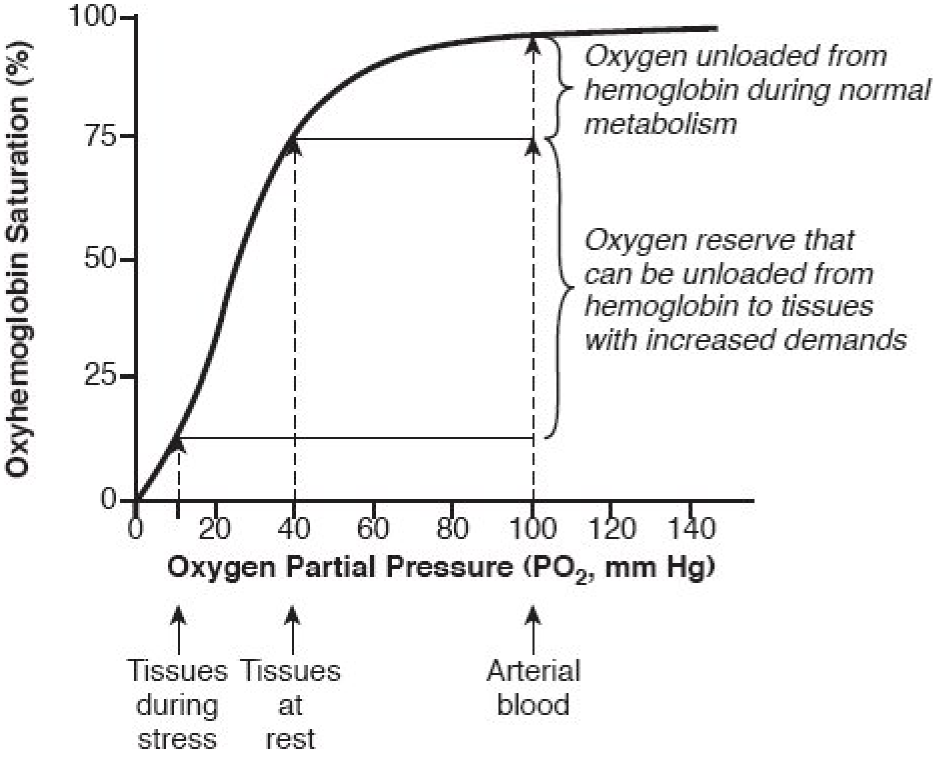
Arterial oxygen content (CaO_2) is defined as the amount of oxygen bound to hemoglobin plus the amount of oxygen dissolved in arterial blood plasma. The components of arterial oxygen content are related by the formula:

$$CaO_2(\text{mL } O_2/\text{dL}) = [\text{Hemoglobin (g/dL)} \times 1.34 \times SaO_2(\%)] + [0.0031 \times PaO_2(\text{mm Hg})]$$

SaO_2 is the arterial oxyhemoglobin saturation and PaO_2 is the partial pressure of oxygen dissolved in arterial blood. Each fully saturated gram of hemoglobin transports 1.34–1.39 mL of oxygen, depending on the affinity of hemoglobin for oxygen. Hemoglobin is the major contributor of oxygen for tissue demands and releases bound oxygen based on cellular uptake of dissolved oxygen as blood flows through the capillaries. The ability of hemoglobin to release more oxygen when supply is inadequate or cellular demand is increased is one of the main compensatory mechanisms to sustain cellular function. The oxyhemoglobin dissociation curve shows the relationship of hemoglobin saturation and partial pressure of oxygen (PaO_2) (**Figure 7-1**).

The major determinants of oxygen delivery are hemoglobin, SaO_2*, and cardiac output.*

Figure 7-1. Oxyhemoglobin Dissociation Curve



The oxyhemoglobin dissociation curve relates the PO_2 to oxyhemoglobin saturation. Near-maximal saturation of hemoglobin occurs at a PO_2 of 60 mm Hg (8.0 k Pa). PO_2 values above this point provide only a modest increase in oxyhemoglobin saturation. Note, however, that a rapid decrease in oxyhemoglobin saturation occurs when the PO_2 drops below 60 mm Hg (8.0 k Pa).

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Stored packed red blood cells rapidly lose a substance called 2,3-diphosphoglycerate (2,3 DPG). This results in an impairment in oxygen transport to tissues.

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When the PaO_2 drops to approximately 40 mm Hg (5.3 kappa) in the capillaries, the decrease in oxyhemoglobin saturation to 75% reflects the amount of oxygen released to the tissues. During physiologic stress, oxyhemoglobin saturation at the tissue level may decrease to <20%, reflecting the release of additional oxygen to tissues. Acidosis, fever, and increased CO_2 production will shift this curve to the right, resulting in a lower affinity of oxygen for hemoglobin and greater delivery of oxygen to the tissues. Lower temperature, higher pH, and lower CO_2 will shift the curve to the left and increase the affinity of oxygen for hemoglobin. In other words, a shift to the right will result in more oxygen being delivered to the tissues.

> !
>
> *Calculated CaO_2 reflects oxygen that is available in the arterial circulation and not necessarily the oxygen that is delivered to or consumed by specific tissues.*
>
> !

Arterial oxygen content can be estimated by using the direct measurement of the hemoglobin concentration and arterial oxyhemoglobin saturation in intermittent blood samples because dissolved oxygen ($0.0031 \times PaO_2$) contributes minimally to oxygen content. Although hemoglobin is not monitored continuously, oxyhemoglobin saturation measured by pulse oximetry (SpO_2) allows continuous assessment of this determinant of arterial oxygen content.

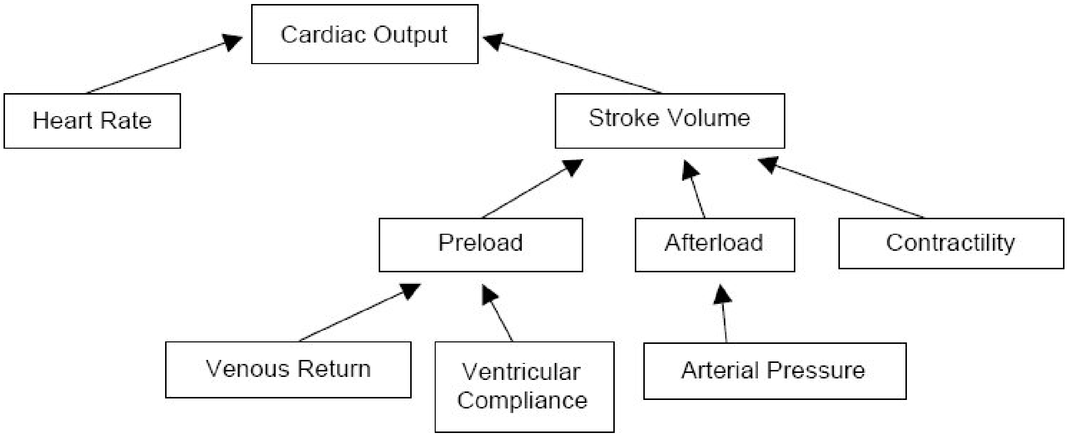
B. Cardiac Output

In addition to the oxygen content of arterial blood being optimum, an appropriate cardiac output is needed to ensure delivery of oxygen to the tissues. Monitoring tools aside, the evaluation of a critically ill patient begins with a thorough clinical examination (**Table 7-1**). Cardiac output (in mL/min or L/min) is the product of heart rate and stroke volume (**Figure 7-2**).

Table 7-1 Clinical Assessment of Determinants of Cardiac Output

Variable	**Method of Assessment**
Heart rate and rhythm	Finger on pulse Pulse oximetry Electrocardiography
Preload	
Right heart	Neck vein distension, liver enlargement, dependent edema Presence of dyspnea on exertion, orthopnea Assessment of central venous pressure can help understand right heart filling/preload conditions.
Left heart	Pulmonary edema, rales on lung examination
Afterload (left heart)	Skin temperature and moisture • Cold and clammy, generally alludes to high afterload in shock state • Hot, flush +/- diaphoretic alludes to low afterload in shock state
Contractility	Ejection fraction and stroke volume estimate by echocardiography

Figure 7-2. Cardiac Output as the Product of Heart Rate and Stroke Volume


Cardiac Output
Heart Rate
Stroke Volume
Preload
Afterload
Contractility
Venous Return
Ventricular Compliance
Arterial Pressure

!

Persistent tachycardia should be considered as a possible compensatory mechanism to increase oxygen delivery.

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Stroke volume is the quantity of blood pumped out of the left heart with each beat and is determined by the difference between the end-diastolic volume and end-systolic volume of the ventricle. Variables that determine stroke volume are preload, afterload, and contractile function. The first compensatory mechanism to increase oxygen delivery is often an increase in heart rate. Patients who are unable to increase their heart rate (eg, beta-blockade or fixed pacing) will have a limited ability to compensate.

Although the heart rate is easily measured and evaluated, an evaluation of stroke volume requires special noninvasive, minimally invasive, or invasive methods. The option of measuring cardiac output by assessing stroke volume depends on the training, expertise, and resources available. The pulmonary artery catheter is used as an invasive method of measuring intermittent or continuous cardiac output but requires critical care expertise. Minimally invasive hemodynamic methods measure cardiac output using analysis of the arterial waveform or aortic blood flow. Devices that analyze the arterial waveform to determine pulse pressure, stroke volume, and cardiac output require an arterial catheter, and some also require placement of a central venous catheter. Esophageal Doppler devices estimate cardiac output from measurement of blood flow in the descending aorta. Noninvasive hemodynamic monitors use principles of bioimpedance or bioreactance to determine stroke volume and cardiac output.

The clinician must be aware of the limitations that affect measurement accuracy and interpretation of any chosen technique. If cardiac output is not directly measured, an indirect assessment of variables involved in determining cardiac output can be determined clinically (**Table 7-2**) and knowledge of hemodynamic principles can be useful.

Table 7-2 Devices to Measure Cardiac Output or Stroke Volume

Level	Devices	Benefits	Risks/Concerns
Invasive	Pulmonary artery catheter (PAC)	Most reliable	Infections, bleeding, pulmonary embolism, pulmonary artery rupture, pneumothorax, dysrhythmias
Minimally invasive	Arterial line-operated devices	Least invasive. In addition to cardiac output and stroke volume, displays stroke volume variation/pulse pressure variation.	Accuracy. Calibration. Unknown patented algorithms. Costly.
	Esophageal Doppler	Accurate assessment of aortic blood flow velocity/timing in order to monitor stroke volume and cardiac output	Costly. Requires training for insertion and interpretation. Risk of bleeding and esophageal perforation.
Noninvasive	Bioimpedance, bioreactance (more accurate)	Not invasive	Less accurate, better with trends

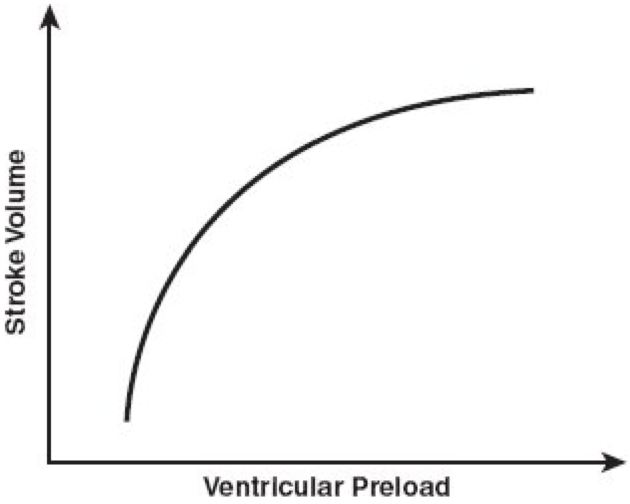
1. Contractility

Contractility is the ability of myocardial fibers to shorten during systole. It is highly dependent on preload and afterload and is difficult to measure as an independent variable. Systemic factors that can affect contractility in the critically ill patient are endogenous sympathetic activation, acidosis, ischemia, inflammatory mediators, and vasoactive agents. An increase in contractility would result in a larger stroke volume. Echocardiographic measurement of the ejection fraction provides some information to the clinician on contractility.

2. Preload

Preload is a measure or estimate of the ventricular volume at the end of diastole (end-diastolic volume) and is determined by venous return and ventricular compliance. The distensibility or stretch (compliance) of the ventricle and the volume load (venous return) it can accept are the basis for the Frank-Starling curve. In general, a greater end-diastolic volume leads to increased stretch on the myocardium, resulting in a larger stroke volume and therefore, better cardiac output. The curve is actually bell-shaped and too much fluid, thus elevated preload, can lead to overstretch of the ventricle, leading to decreased stroke volume as a result of the loss of effective contractility (**Figure 7-3**). Because it is difficult to measure volume, preload is most often estimated from the ventricular end-diastolic pressure, which is transmitted and reflected in the atrial pressure. The atrial pressure is estimated by the measurement of pressure in a central vein or the pulmonary artery. Thus, the right ventricular preload is estimated by measurement of the central venous pressure (CVP) and the left ventricular preload by the measurement of pulmonary artery occlusion pressure (PAOP). These pressures indirectly reflect the end-diastolic volume as well as the compliance of the ventricular wall. Using bedside ultrasonography, assessment of the size and variability of the inferior vena cava with respiration may aid in the assessment of right ventricular preload. However it should not be used independently because it is not sensitive or specific enough to predict volume responsiveness.

Figure 7-3. Relationship Between Ventricular Preload and Stroke Volume:



When end-diastolic volume of the ventricle (preload) increases, stroke volume usually increases proportionately.

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Pressure and volume are not linear, CVP and PAOP should not be used alone to determine *volume status. Trends are more beneficial than isolated values.*

The relationship between the measured pressure and volume in the ventricular chambers depends on the compliance or distensibility of the ventricle. During myocardial ischemia, sepsis, valvular dysfunction, and even tachycardia, the ventricles may become less compliant and may not fully relax during diastole. This diastolic dysfunction reduces the ventricular volume at end diastole but may be associated with a higher filling pressure; therefore, the clinician may misinterpret pressure measurements to indicate adequate volume loading. Changes in intrathoracic pressures (eg, tension pneumothorax, positive pressure ventilation) may also affect the filling pressures.

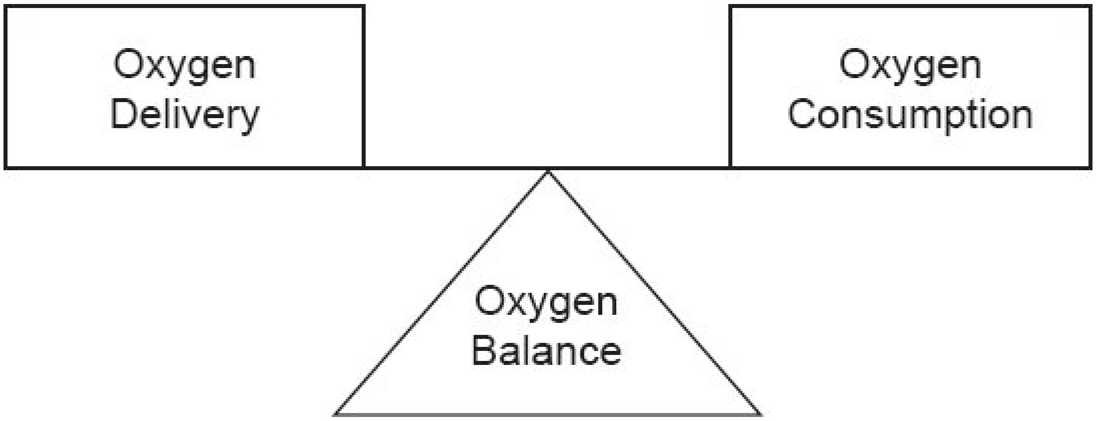
3. Afterload

Afterload is the myocardial wall tension required to overcome the resistance, or pressure load, that opposes ejection of blood from the ventricle during systole. The higher the afterload, the more tension the ventricle must develop, the more work is performed, and the less efficient the contraction may become. Afterload is usually estimated from the systemic mean arterial pressure (left ventricle) and mean pulmonary artery pressure (right ventricle) by calculations of systemic and pulmonary vascular resistance.

III. ASSESSMENT OF OXYGEN BALANCE

In addition to oxygen delivery, oxygen consumption by the tissues affects oxygen balance (**Figure 7-4**). Several factors can increase oxygen consumption in a critically ill patient including but limited to: pain, agitation, anxiety, seizures, piloerection, shivering, fever, and increased work of breathing. However, less is known about the factors that determine oxygen utilization at the cellular and tissue levels, and no direct routine measures of oxygen consumption are available. Indirect calculated measurement of oxygen consumption requires invasive or complex techniques. These measures reflect global oxygen utilization and do not provide information on oxygen utilization by specific tissues or organs.

Figure 7-4. Oxygen Balance



Measuring global oxygen balance may be useful in monitoring the critically ill patient. The goal of resuscitation in a critically ill patient is to ensure an appropriate oxygen balance. When there is not an oxygen balance, and consumption is higher than delivery for an organ, the organ is ischemic. Ischemia leads to organ failure as the organ shifts from aerobic to anaerobic metabolism. Minimally invasive measurements of global oxygen balance include central venous oxyhemoglobin saturation ($ScvO_2$) and lactate concentrations.

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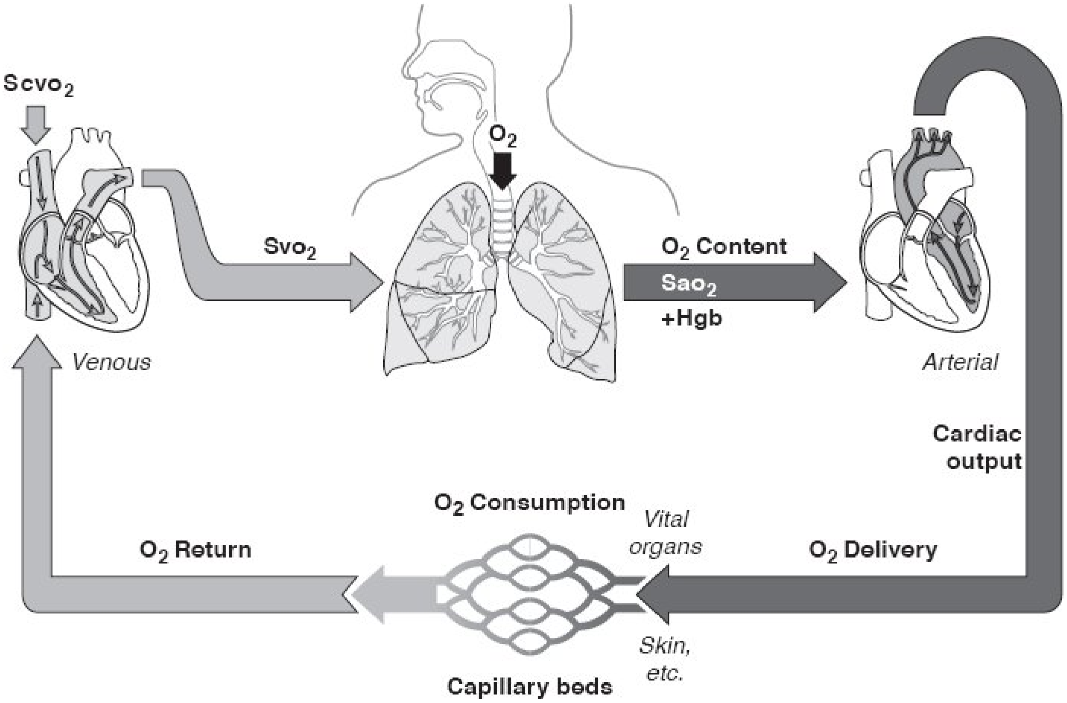
Normal SvO_2 is >65%.
Normal $ScvO_2$ is >70%.

!

$ScvO_2$ can be obtained continuously or intermittently from a catheter placed in the internal jugular or subclavian vein and correlates with the mixed venous oxyhemoglobin saturation (SvO_2) obtained from a pulmonary artery catheter in the pulmonary artery. The SvO_2 measures the oxyhemoglobin saturation of blood from the whole body that has been mixed in the pulmonary artery. These measures of venous oxyhemoglobin saturation represent the amount of oxygen still bound to hemoglobin after traversing the tissue capillaries and returning to the right heart; the difference between the SaO_2 and SvO_2 estimates the amount of oxygen used (**Figure 7-5**). In normal individuals, the SvO_2 is $>65\%$ and the $ScvO_2$ is 2% to 3% lower. However, in patients with shock and/or hypoperfusion, the $ScvO_2$ may be 5% to 7% higher than the SvO_2 because of greater desaturation of venous blood from the gastrointestinal tract contributing to SvO_2. Low values of $ScvO_2$ suggest an imbalance in the oxygen supply and demand. This imbalance may be caused by decreases in cardiac output, hemoglobin concentration, SaO_2, or increases in tissue oxygen consumption. Patients may have more than one abnormality contributing to oxygen imbalance. A normal $ScvO_2$ may still be associated with tissue hypoxia in conditions such as severe sepsis and certain poisonings (eg, cyanide). Further evaluations of lactate concentration and organ function are needed to assess oxygen balance in the seriously ill patient when the $ScvO_2$ is normal.

Figure 7-5. Determinants of Oxygen Balance



Scvo$_2$
O$_2$
Svo$_2$
O$_2$ Content
Sao$_2$
+Hgb
Venous
Arterial
Cardiac output
O$_2$ Consumption
Vital organs
O$_2$ Return
O$_2$ Delivery
Skin, etc.
Capillary beds

Abbreviations: Hgb, hemoglobin; SaO_2, arterial oxyhemoglobin saturation

Oxygen balance depends on the oxygen delivered to the tissues and the metabolic needs of those tissues. An estimate of the oxygen utilized by the tissues is provided by the central venous oxyhemoglobin value ($ScvO_2$ and mixed venous oxyhemoglobin saturation (SvO_2).

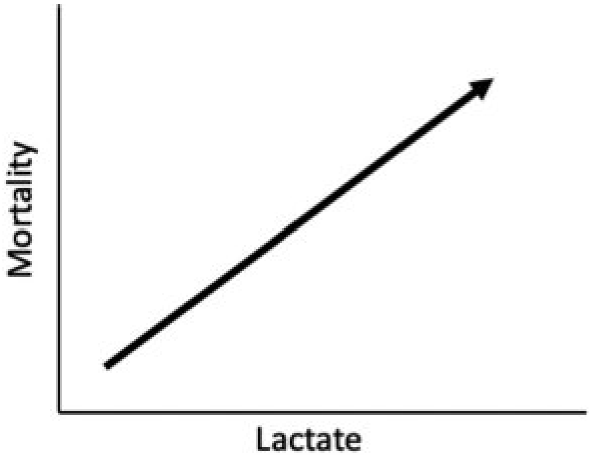
!

*Elevated lactate concentrations correlate with a worse prognosis in severely ill patients (**Figure 7-6**).*

!

Lactate is another indicator of the overall oxygen balance. It is produced during anaerobic metabolism when cellular hypoxia occurs. The elevation of blood lactate in shock and hypoperfusion may be the result of an inadequate oxygen supply to tissue but also may be affected by altered hepatic metabolism, use of vasoactive drugs, and other factors. Lactate concentrations do not have high sensitivity or specificity for inadequate tissue oxygenation, but elevated concentrations often are associated with tissue hypoperfusion. A decreasing lactate concentration may be a useful indicator of effective interventions.

Figure 7-6. Lactate and Mortality



Capillary refill time is another useful tool. It is a simple clinical maneuver that may assist with evaluation of oxygen delivery and hemodynamic resuscitation in a critically ill septic patient.

Case Study (cont.)

A 67-year-old woman with a medical history of hypertension, diabetes mellitus, and systolic heart failure (LVEF 20%) presented to the hospital with altered mental status and shortness of breath. The patient's pulse is 123 beats/min, blood pressure 84/54 mm Hg, respiratory rate 28 breaths/min and oxygen saturation on pulse oximetry (SpO_2) 89% while breathing room air. She was found to have a lower gastrointestinal bleed.

- What factors may lead to poor oxygen delivery?
- What monitoring strategies would be employed to assess the condition of this patient?

IV. MONITORING DETERMINANTS OF OXYGEN BALANCE

Trends in the values of measured variables are usually more helpful than single values.

Precise monitoring of oxygen balance is not easily accomplished because special expertise, invasive monitoring, and significant resources are required. However, monitoring of variables, such as oxyhemoglobin saturation, blood pressure, $ScvO_2$, lactate concentration, and fluid responsiveness combined with other clinical information, may provide guidance in evaluating the adequacy of oxygen balance in seriously ill patients.

A. Monitoring of Oxyhemoglobin Saturation

1. Principles

The pulse oximeter is a simple, noninvasive device that estimates arterial oxyhemoglobin saturation. The transmission of red and infrared light through the capillary bed creates several signals throughout the pulsatile cardiac cycle. These signals measure the absorption of the transmitted light by the tissue or venous and arterial blood. Calculations made from the processed signals provide estimates of the oxygen saturation of hemoglobin, expressed as a percentage. This is not the same as the PaO_2 in the blood, although PaO_2 is the primary determinant of the saturation of hemoglobin. It does not reflect adequacy of oxygen delivery or ventilation. The value measured by the device is commonly called the SpO_2 to distinguish it as the oxyhemoglobin saturation measurement by a pulse oximeter rather than the SaO_2, which is determined directly from an arterial blood sample by co-oximetry. Pulse oximetry is useful in detecting hypoxemia and titrating the delivered oxygen concentration in patients receiving supplemental oxygen.

2. Clinical Issues

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Pulse oximetry measurements will be affected by inflation of a blood pressure cuff on the same extremity as the oximetry sensor because of disappearance of the pulsatile waveform.

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Studies have shown that to ensure a PaO_2 of 60 mm Hg (8.0 k Pa), an SpO_2 of 92% should be maintained in patients with light skin, whereas 94% saturation may be needed in patients with dark skin. Oximetry sensors can be applied to the finger, toe, earlobe, bridge of nose, forehead, or any skin surface from which a reliable pulsatile signal can be obtained. Factors that can affect signal detection or fidelity are listed in **Table 7-3**. Pulse oximeters display a digital heart rate derived from the pulsatile signal detected by the sensor. This rate should equal the patient's heart rate as measured by another method, so these two rates should be compared as the first step in the analysis of an SpO_2 measurement.

Table 7-3 Factors That Affect Accuracy of Pulse Oximetry

Anatomic or Physiologic Factors

Dark skin
False nails
Nail polish
Hypothermia
Vasoconstriction
Hypotension
Poor regional perfusion
Hematocrit <15%
Hyperlipidemia
Carboxyhemoglobin
Tachycardias

External Factors

Lipid suspensions, propofol (falsely elevate the oxygen saturation)
Bright room lighting
Electrical interference
Poorly adherent probe
Excessive motion of the sensor

B. Blood Pressure Monitoring

Although blood pressure is not a direct determinant of oxygen balance, an appropriate driving pressure is necessary for oxygen delivery at the tissue level. Blood pressure is directly proportional to cardiac output and systemic vascular resistance according to the following relationship:

$$\text{Blood pressure} = \text{cardiac output} \times \text{systemic vascular resistance}$$

Blood pressure may be monitored invasively, with arterial cannulation, or noninvasively with a cuff.

1. Automated Noninvasive Devices

a. Principles

Automated blood pressure devices are frequently used to obtain intermittent blood pressure measurements. These devices use one of several methods to measure systolic and diastolic pressures, but the most common method is oscillometry. Systolic and diastolic pressures and the mean arterial pressure are directly measured via appearance, disappearance, and amplitude of oscillating waves. The arm is the preferred measurement site in adults, but alternative sites include the calf, forearm, or thigh, the latter being the least comfortable site for patients. The cuff should not be placed on an extremity that is being used for intravenous infusion or in an area susceptible to circulatory compromise. The appropriate cuff size is necessary for accurate measurements. A cuff that is too large will underestimate the true blood pressure, and a cuff that is too small will overestimate the true blood pressure.

b. Clinical Issues

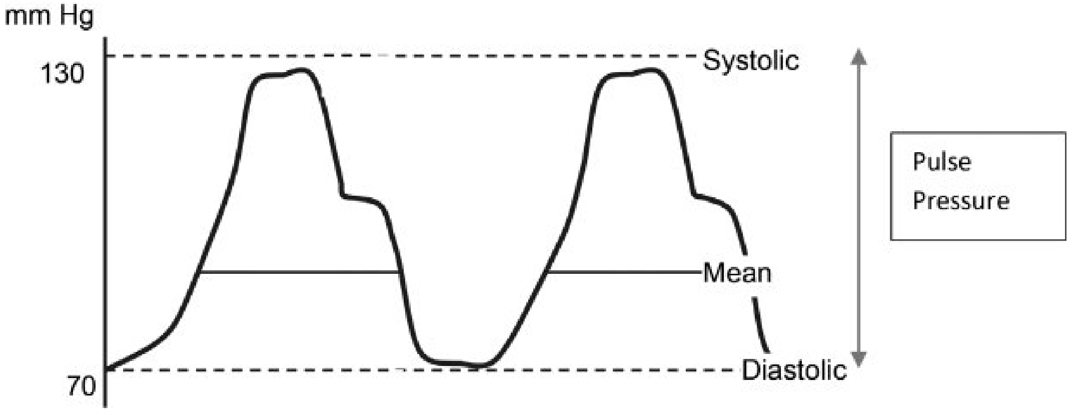
An adequate blood pressure measurement does not ensure adequate tissue perfusion. Automated blood pressure devices are less accurate in clinical situations commonly encountered with the critically ill patient, such as shock, vasoconstriction, mechanical ventilation, and arrhythmias. Shivering, muscle contraction, and movement of the extremity can lead to erroneous measurements. Blood pressure monitoring via an arterial catheter is preferable to the use of an automated blood pressure device in hemodynamically unstable patients.

2. Arterial Cannulation

a. Principles

An indwelling arterial catheter allows for continuous measurement of blood pressure, pulse volume or pressure, and mean arterial pressure (**Figure 7-7**) by transduction of pressure via a specialized monitoring setup. Pulse pressure is the difference between the systolic and diastolic pressure measurements. It may also be used for arterial blood gas measurement. The primary indications for insertion of an arterial cannula are the need for frequent arterial samples and continuous assessment of arterial blood pressure. Use of an arterial catheter should be considered for arterial blood sampling if more than four samples are required in 24 hours. Arterial pressure monitoring may also be used with minimally invasive hemodynamic monitoring systems to evaluate cardiac output, stroke volume, or pulse pressure variation.

Figure 7-7. Appearance of Arterial Pressure Wave with Invasive Monitoring



When invasive monitoring is used, the calculation of the mean arterial pressure is based on the area under the curve.

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The dorsalis pedis artery is less reliable for pressure monitoring in adults because of its size and distance from the heart.

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The most common insertion sites for arterial catheters are (in order of preference for adults) the radial, femoral, axillary, and dorsalis pedis arteries. Brachial artery cannulation is usually avoided if possible because it is an end artery and hand ischemia is a potential complication. Shorter catheters are used for radial and dorsalis pedis artery insertion and longer catheters for insertion in femoral and axillary sites. Preferred sites have alternative collateral circulations. The choice of site is based on the presence of palpable pulses, general hemodynamic state, and other anatomic or physiologic factors unique to each patient.

b. Clinical Issues

The arterial catheter is never used for infusion of any medications or fluids and must be monitored continuously. Concern about the accuracy of the intra-arterial pressure measurements should lead to a return-to-flow assessment with a manual blood pressure cuff. Measurements should be made after calibration of the catheter/transducer system at or near the level of the heart.

Several technical and anatomic factors may affect the accuracy of the pressures obtained with the catheter system. Distortion of the arterial waveform signal may occur because of vascular alterations, the hydraulic coupling system of the transducer, the calibration of the transducer, or the maintenance of the pressurized system tubing.

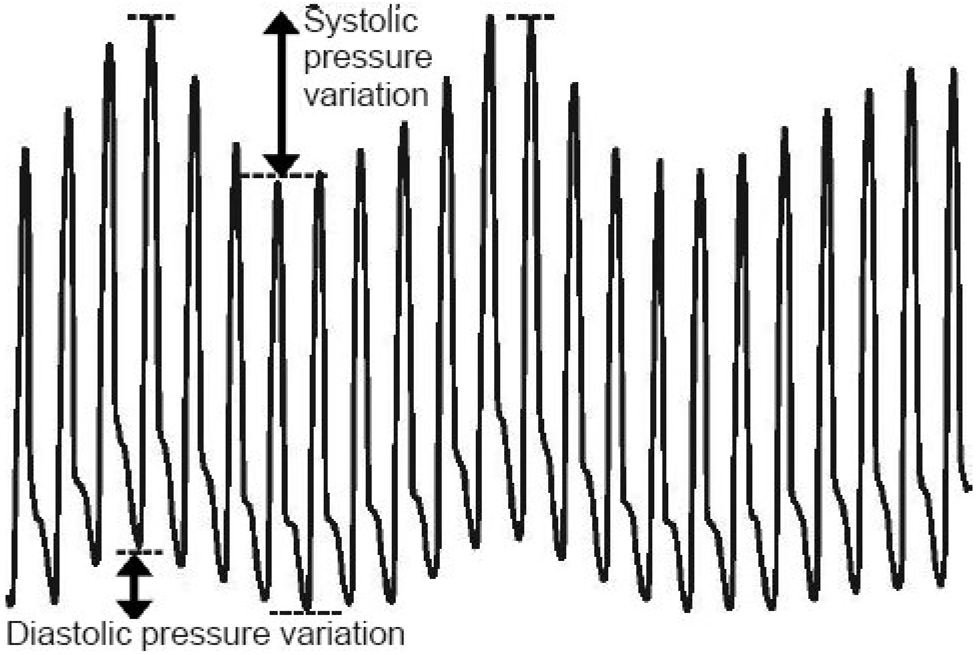
Inspection of the result may show an overdamped and domed waveform or the high-spiking "overshoot or ringing" pattern of the underdamped waveform. Both distortions have the greatest effect on the systolic and diastolic pressures, whereas the mean arterial pressure is less affected.

Pulse Pressure = Systolic Pressure – Diastolic Pressure
Normal = 30–40 mm Hg

Hypotension is not always associated with the presence of shock or tissue hypoperfusion.

As with noninvasive monitoring, intra-arterial blood pressure monitoring may not be a sensitive indicator of hypoperfusion because of compensatory vasoconstriction. Additional clinical information regarding volume status can be obtained by visual inspection of the arterial blood pressure waveform in mechanically ventilated patients (**Figure 7-8**). Positive pressure during inspiration may decrease the stroke volume in patients with inadequate intravascular volume because of decreased venous return. The decrease in stroke volume leads to a decreased pressure that is visually represented as a systolic variation of blood pressure and a decrease in the pulse pressure.

Figure 7-8. Variation of Blood Pressure in a Mechanically Ventilated Patient with Hypovolemia



With positive pressure applied during inspiration, the decrease in systolic pressure is greater than the decrease in diastolic pressure, resulting in a decrease in pulse pressure.

Possible complications associated with arterial catheter insertion are listed in **Table 7-4**. These can be minimized by careful insertion technique, appropriate catheter size for the artery, proper site care, and a continuous flush system. The arterial waveform must be continuously monitored and displayed, with alarm settings to prevent inadvertent blood loss through a catheter that is accidentally opened to the atmosphere. The extremity with the arterial catheter should be inspected frequently for evidence of ischemia or infection. Any sign of ischemia distal to the catheter or infection at the site of insertion requires immediate removal of the catheter. Arterial catheters should be removed as soon as possible to minimize the risk of infection.

Table 7-4 Possible Complications of Arterial Catheters

Hematoma formation
Blood loss
Arterial thrombosis
Proximal or distal embolization
Arterial pseudoaneurysm
Infection
Accidental administration of fluids or medications

C. Monitoring Right Ventricular Filling Pressures and $Scvo_2$

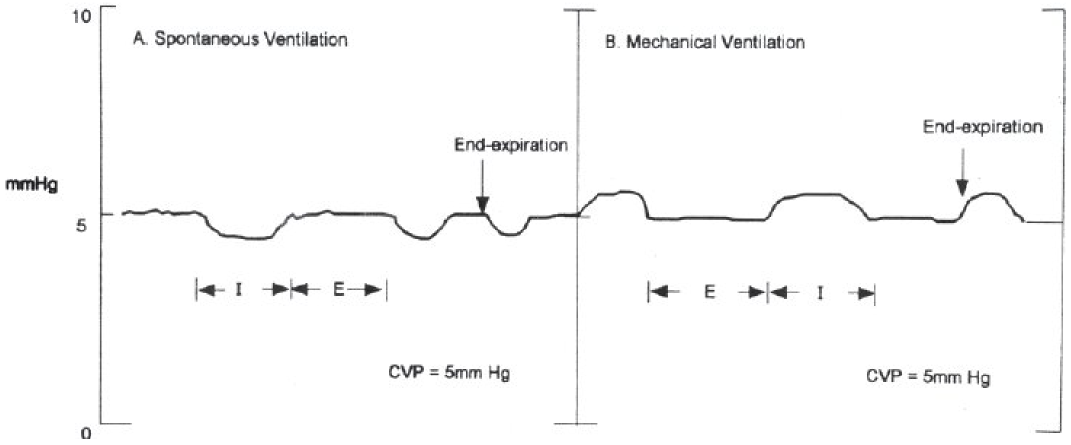
A central venous catheter in the internal jugular or subclavian vein allows measurement of CVP and $ScvO_2$. Placement of a central venous catheter may be indicated for other reasons as well (**Table 7-5**). Confirmation of catheter placement in the internal jugular or subclavian vein and the tip in the superior vena cava by chest radiography is recommended to ensure accurate measurements of CVP and $ScvO_2$ and to detect complications of the procedure.

Table 7-5 Common Indications for Central Venous Cannulation

Measurement of mean central venous pressure
Measurement of central venous oxygen saturation
Large-bore venous access
Difficult or long-term venous access
Administration of irritating drugs and/or parenteral nutrition
Hemodialysis
Placement of a temporary pacing wire
Placement of a pulmonary artery catheter

CVP, obtained from an appropriately positioned catheter, estimates the right ventricular filling pressure as a reflection of preload (end-diastolic volume). Normal values for CVP are 2 to 6 mm Hg, and measurements should be made at the end of expiration. Significant variation of the CVP waveform may occur during spontaneous breathing and mechanical ventilation, requiring visual assessment of the waveform to identify the end of expiration (**Figure 7-9**). In general, a low CVP indicates a low intravascular volume associated with a low preload. Normal or high CVP measurements must be evaluated cautiously because they may not predict adequate or increased preload volume caused by changes in intrathoracic pressure or ventricular compliance. Assessment of fluid responsiveness is necessary to estimate adequacy of preload with normal or elevated CVP measurements. Right ventricular preload estimates do not necessarily correlate with left ventricular preload.

Figure 7-9. Typical Cyclic Pattern for CVP Waveform



Typical cyclic pattern for continuous venous pressure (CVP) waveform that shows inspiration (I) and expiration (E). A, Respiratory variation during spontaneous ventilation: CVP decreases during spontaneous inspiration as intrapleural pressure decreases. B, Respiratory variation during positive pressure mechanical ventilation: CVP increases during delivery of the mechanical breath as positive pressure is transmitted from the airway to the intrapleural space and great vessels. The vertical arrows denote the point of end-expiration during spontaneous and mechanical ventilation.

$ScvO_2$ can be monitored intermittently by withdrawal of blood for analysis or continuously with a catheter containing an oximeter to evaluate oxygen balance. Clinical protocols have used $ScvO_2$ measurements along with other parameters to determine adequacy of resuscitation. Normal $ScvO_2$ values are usually 70%.

D. Measuring Left Ventricular Filling Pressures

Left ventricular filling pressures are usually estimated from measurement of the PAOP. A pulmonary artery catheter is necessary to obtain this information but requires expertise in insertion, data collection, and data interpretation. Static single measurements of left ventricular filling pressure can often be provided by echocardiography.

E. Measuring Cardiac Output

Cardiac output plays a key role in determining oxygen delivery to the tissues. Measurement methods, such as thermodilution with a pulmonary artery catheter, esophageal Doppler ultrasonography, and arterial waveform pulse pressure analysis, require varying degrees of invasiveness as well as special expertise. In the absence of direct measurement of cardiac output, less-specific indicators of tissue oxygenation, such as lactate concentration and $ScvO_2$, may guide specific interventions. A calculated value for cardiac output can be achieved by using hemodynamic parameters along with laboratory analysis of arterial blood gas, hemoglobin, and central venous blood gas. This calculation is readily available online (search "FICK equation calculator") and gives an additional tool for resource-limited areas to monitor/trend cardiac output.

V. TREATMENTS FOR A NEGATIVE OXYGEN BALANCE

After monitoring devices have been initiated and the patient has been determined to be in a negative oxygen balance, resuscitation should be continued until the balance has been restored. The first step in management is to identify and reverse the underlying cause of the organ failure/shock. Multiple disease processes reduce oxygen delivery or increase or alter oxygen consumption (**Table 7-6**). In addition, resuscitation usually involves increasing oxygen delivery because it is easier to alter than oxygen consumption. At its core, resuscitation goals are to increase cardiac output, hemoglobin, or oxygen saturation to improve oxygen delivery. Cardiac output is dependent on preload, contractility, and afterload. A step-by-step process for restoring oxygen delivery to the tissues will be discussed in the following paragraphs.

Table 7-6 Disorders/Factors That Can Affect Oxygen Delivery

Pulmonary (Hypoxemia)	Cardiac	Miscellaneous
Hypoventilation	Low cardiac output	Severe anemia
V/Q mismatch	Right to left intracardiac shunt	Methemoglobinemia
Pulmonary shunt		Carboxyhemoglobinemia
Dead space		Mitochondrial disorders
Diffusion limitation		
High altitude		

A. Cardiac Output

1. Fluid/Volume Responsiveness (Preload)

The practical question that clinicians often face in caring for critically ill patients is whether further fluid administration will improve cardiac output and oxygen delivery. This dilemma is not adequately addressed by single measurements of heart rate, CVP, or blood pressure. It is important to recognize that subpar fluid resuscitation can lead to inadequate perfusion. It should be equally understood that overzealous administration of fluids can have deleterious effects. In fact, only about 50% of unstable critically ill patients respond to fluid administration.

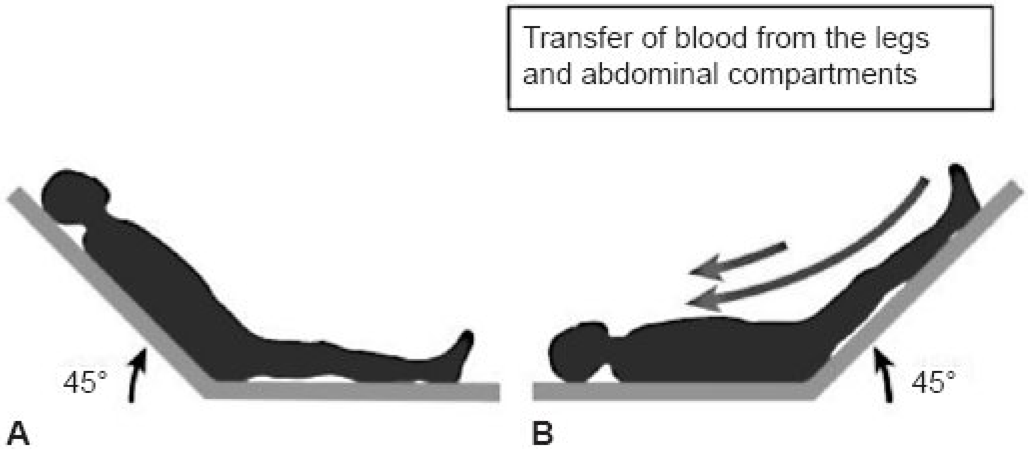
Significant variation in the cardiac output, stroke volume, systolic blood pressure, or pulse pressure in mechanically ventilated patients with evidence of impaired oxygen delivery may suggest the need for additional fluids to optimize cardiac output. With each positive pressure breath from the ventilator, venous return and right ventricular preload is decreased. If the right ventricle is dependent on preload, then positive pressure breaths will result in a decrease in the right ventricular stroke volume, leading to a decrease in left ventricular preload and left ventricular stroke volume (cardiac output). A variety of devices are available that can monitor variation in systolic blood pressure, pulse pressure, and/or stroke volume. All have limitations in accuracy that must be considered, such as adequate tidal volume, tachyarrhythmias, and adequate sedation.

A patient is deemed to be volume responsive if any of the following hemodynamic parameters are demonstrated:

- Stroke volume increase of 10%–15%
- Stroke volume variation/pulse pressure variation ≥12%
- Cardiac output increase of 10%–15%

Passive leg raising (PLR) is another technique that may be used at the bedside with less invasive monitoring techniques to determine whether additional fluid is beneficial. This maneuver is performed by placing the head of the bed flat from the semi-recumbent position and then raising both legs simultaneously to a 45° angle (**Figure 7-10**). This action results in a gravitational transfer of 250–350 mL of blood from the lower limbs and splanchnic compartment toward the right heart. No fluid is infused and the clinical effects are completely reversible. If a significant increase in cardiac output or stroke volume is noted within 30 to 60 seconds of PLR, the patient is determined to be fluid responsive. PLR has been noted to be reliable in mechanically ventilated patients and patients with spontaneous respiratory effort who are not mechanically ventilated. Although blood pressure and pulse pressure have traditionally been used during PLR, cardiac output and stroke volume changes are much more sensitive in assessing volume responsiveness. No increase or an insignificant increase in blood pressure is less helpful in this circumstance. PLR should not be performed in patients with increased intracranial pressure and may not be reliable when intraabdominal pressures are increased.

Figure 7-10. Effects of Passive Leg Raising



Fluid boluses may also be used to determine whether a patient is fluid responsive. Boluses of isotonic crystalloid (usually 250–500 mL) are administered over a short period (5–10 minutes) and subsequent cardiac output or stroke volume measurements are noted. If a significant increase in cardiac output or stroke volume occurs following the bolus, the patient is fluid responsive. This technique must be used carefully because additional fluid may be detrimental to the patient's cardiac or respiratory status.

2. Mean Arterial Pressure (Afterload)

If oxygen balance is not restored and the patient is found to be adequately fluid resuscitated, the next parameter to regulate is the mean arterial pressure. Addition of vasopressors or vasodilators leads to normalization of afterload leading to an increase in cardiac output.

3. Contractility

Low cardiac output after normalization of preload and afterload requires the addition of intravenous infusion of inotropes. Inotropes increase contractility, thus leading to an increase in stroke volume. Prior to initiation of inotropic agents, a healthcare practitioner should have monitoring of cardiac output established to effectively titrate these medications.

B. Hemoglobin

The patient's hemoglobin is monitored and if the level is <7g/dL (<8g/dL if heart failure/ischemia), then the patient should be considered for a transfusion. Transfusion may be required for hemoglobin levels >8g/dL if the patient is symptomatic. Symptomatic anemia results in hypotension, tachycardia, orthostatic hypotension, fatigue, dizziness with movement, and in extreme cases, hypoxemia. As the transporter of oxygen to the tissues, loss of hemoglobin significantly affects oxygen delivery. Blood transfusions have significant risks on their own and should only be done if necessary.

C. Oxygenation

If the patient's oxygen level is not adequate, supplemental oxygen can be added to ensure appropriate saturation of hemoglobin. Supplemental oxygen can range from a nasal cannula to endotracheal intubation. Treatment of the underlying cause of hypoxemia is important to decrease the length of time supplemental oxygen is required.

VI. ACID-BASE DISORDERS

Acid-base disorders are common in the critically ill patient, and assessment of acid-base status may indicate a specific diagnosis and/or therapeutic interventions. The presence of metabolic acidosis could suggest hypoperfusion and prompt further assessment of the adequacy of the oxygen balance. An appropriate evaluation of acid-base status requires accurate interpretation of simultaneous measurements of electrolytes, albumin, and arterial blood gases, as well as knowledge of compensatory physiologic responses. **Appendix 2** includes acid-base case studies for practice in analyzing arterial blood gas and electrolyte information and in determining appropriate interventions.

A. Evaluation of Acid-Base Disorders

Analysis of acid-base disorders in seriously ill patients requires a systematic approach. Although several methods can be used (base excess, strong ion difference), the approach discussed here relies on traditional analysis using formulas based on hydrogen ion and bicarbonate (HCO_3) concentrations that can be applied at the bedside.

1. Determine the overall acid-base condition by measuring pH. Is acidemia or alkalemia present?
2. If an abnormality is present, determine whether the primary process is metabolic (change in [HCO_3]) or respiratory (change in partial pressure of arterial carbon dioxide [$PaCO_2$]).
3. If a respiratory disturbance is present, determine whether it is an acute or a chronic process.
4. If a metabolic disturbance is present, determine whether respiratory compensation is adequate.
5. Always calculate the anion gap (AG); if needed, correct for albumin.
6. If an anion gap is present, is there another metabolic derangement present?

B. Metabolic Acidosis

Metabolic acidosis results from an increase in endogenous acid production that overwhelms renal excretion (eg, ketoacidosis, lactic acidosis), exogenous acid input (eg, toxin ingestion), excessive loss of bicarbonate (eg, diarrhea), or decreased renal excretion of endogenous acids (eg, renal failure). Compensation is achieved primarily by increasing minute ventilation to eliminate CO_2. The adequacy of respiratory compensation can be estimated by the following formulas:

$$\text{Winter's Formula/Expected } PaCO_2 = 1.5 \times [HCO_3] + 8 \pm 2; \text{ or } \Delta\, PaCO_2 = 1.2 \times \Delta\, [HCO_3]$$

The lower limit of respiratory compensation is usually a $PaCO_2$ of approximately 10 mm Hg (1.3 k Pa). This means the $PaCO_2$ will not go lower than 10 mm Hg to compensate for a metabolic acidosis.

Metabolic acidosis is further characterized by a normal or increased anion gap. Normally, unmeasured anions exceed unmeasured cations, and the difference results in the anion gap (AG). A patient's normal AG is made up of albumin and phosphate, with a normal value of approximately 10 ± 4 mmol/L. An increased AG indicates an increase in unmeasured anions and/or a decrease in unmeasured cations. The patient's AG is calculated using the following formula:

$$AG = Na^{+} - (Cl^{-} + HCO_3^{-})$$

If the patient's calculated AG is higher than the patient's expected normal gap, the patient has an AG metabolic acidosis. An increased AG has limitations as the sole indicator of a metabolic acidosis. In patients with severe hypoalbuminemia, an AG acidosis can exist even when a normal AG is measured. In such patients, the expected normal AG may be as low as 4 to 5 mmol/L. It is imperative to calculate a corrected AG for such patients. A simple rule of thumb: for every albumin decrease of 1 g/dL, a decrease of 2.5 to 3 mmol in the expected normal AG will occur.

In seriously ill patients, the most common causes of metabolic acidosis with an increased AG are lactic acidosis, renal failure, and diabetic ketoacidosis (**Table 7-7**).

Table 7-7 MUDPILES Acronym for Increased Anion Gap Metabolic Acidosis

M	Methanol
U	Uremia
D	Diabetic ketoacidosis
P	Propofol. Propylene glycol. Paracetamol (acetaminophen)
I	Iron. Isoniazid
L	Lactate
E	Ethanol. Ethanol glycol
S	Starvation ketoacidosis. Salicylate

Tachypnea is an early sign of critical illness. An increased respiratory rate may be a compensatory mechanism for metabolic acidosis.

Metabolic acidosis with a normal AG, often called *hyperchloremic acidosis*, may result from gastrointestinal or renal loss of HCO_3 or volume resuscitation with normal saline (**Table 7-8**).

Table 7-8 HARD UP Acronym for Normal Anion Gap Metabolic Acidosis

H	Hyperchloremia
A	Acetazolamide
R	Renal tubular acidosis
D	Diarrhea
U	Ureteroenterostomy
P	Pancreatico-enterostomy

C. Metabolic Alkalosis

Metabolic alkaloses are usually separated into chloride-responsive (most common) and chloride-resistant. A urine chloride level is needed to distinguish between these two categories. A urine chloride <20 mmol/L is seen in chloride-responsive metabolic alkalosis and a urine chloride >20 mmol/L is seen in chloride-resistant metabolic alkalosis. Diuretic therapy is a common cause of hypochloremic metabolic alkalosis in hospitalized patients. Normal compensation for metabolic alkalosis is hypoventilation; $PaCO_2$ may rise 6 to 7 mm Hg (0.8–0.9 k Pa) for every increase of 10 mmol/L in HCO_3. Treatment includes chloride replacement for chloride-responsive states and assessment of the renal-adrenal axis for chloride-resistant conditions. Hypokalemia is common to both types and should be corrected. Severe alkalemia is associated with high mortality and requires aggressive treatment.

D. Respiratory Acidosis

Respiratory acidosis is most commonly the result of ineffective alveolar ventilation. If the respiratory acidosis is acute, the pH decreases by 0.08 units for each increase of 10 mm Hg (1.3 k Pa) in $PaCO_2$. A very small increase in plasma HCO_3 can be seen acutely because of titration of intracellular non-bicarbonate buffers. For each acute increase of 10 mm Hg (1.3 k Pa) in

$PaCO_2$, the HCO_3 increases by 1 mmol/L to a maximum of 30 to 32 mmol/L. In chronic respiratory acidosis, the pH decreases 0.03 units and the HCO_3 increases 3.5 mmol/L for each increase of 10 mm Hg (1.3 k Pa) in $PaCO_2$. The limit of normal renal compensation in chronic respiratory acidosis is an HCO_3 of approximately 45 mmol/L. Higher values suggest an associated metabolic alkalosis. Treatment of respiratory acidosis involves the rapid identification of the etiology and implementation of corrective action. In some circumstances, intubation and mechanical ventilation may be necessary to support alveolar ventilation.

E. Respiratory Alkalosis

Respiratory alkalosis results from primary hyperventilation that is the result of a variety of etiologies. Acute pulmonary processes or an acidosis should be considered in the seriously ill patient. Similar to changes noted in respiratory acidosis, pH increases 0.08 for every decrease of 10 mm Hg (1.3 k Pa) in $PaCO_2$ in acute respiratory alkalosis, and pH increases 0.03 for each decrease of 10 mm Hg (1.3 k Pa) in $PaCO_2$ in chronic respiratory alkalosis. The $[HCO_3]$ decreases 2 mmol/L in acute respiratory alkalosis and 5 mmol/L in chronic respiratory alkalosis for each decrease of 10 mm Hg (1.3 k Pa) in $PaCO_2$. Chronic respiratory alkalosis is unique among acid-base disorders in that pH may return to normal if the condition is prolonged. Therapy is directed to the underlying cause.

F. Complex Acid-Base Disorders

Simple acid-base disorders result from a single process such as metabolic alkalosis. In many critically ill patients, multiple acid-base disturbances exist concurrently and result in complex acid-base disorders. For example, sepsis often presents with respiratory alkalosis and metabolic acidosis. A systematic approach to acid-base analysis is needed to identify the ongoing disturbances and determine appropriate diagnoses and interventions. Formulas that are helpful in evaluating acid-base status are listed in **Table 7-9**.

Table 7-9 Acid-Base Formulas

Acid-Base Disorder	**Equation**
Respiratory Acidosis	
Acute	Decrease in pH = $0.08 \times \frac{(\text{Paco}_2 - 40)}{10}$ Increase in $[\text{HCO}_3] = \frac{\Delta\text{Paco}_2 \pm 3}{10}$
Chronic	Decrease in pH = $0.03 \times \frac{(\text{Paco}_2 - 40)}{10}$ Increase in $[\text{HCO}_3] = \frac{3.5 \times \Delta\text{Paco}_2}{10}$
Respiratory Alkalosis	
Acute	Increase in pH = $0.08 \times \frac{(40 - \text{Paco}_2)}{10}$ Decrease in $[\text{HCO}_3] = \frac{2 \times \Delta\text{Paco}_2}{10}$
Chronic	Increase in pH = $\frac{0.03 \times (40 - \text{Paco}_2)}{10}$ Decrease in $[\text{HCO}_3] = \frac{5 - 7 \times \Delta\text{Paco}_2}{10}$
Metabolic Acidosis	Anion Gap = $[\text{Na}] - ([\text{Cl}] + [\text{HCO}_3])$ Expected $\text{Paco}_2 = 1.5 \times [\text{HCO}_3] + 8 \pm 2$ or expected $\Delta\text{Pco}_2 = 1.2 \times \Delta[\text{HCO}_3]$
Metabolic Alkalosis	Increase in $\text{Paco}_2 = 0.6 - 0.7 \times \Delta[\text{HCO}_3]$

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Key Points

Monitoring Oxygen Balance and Acid-Base Status

- Oxygen delivery is dependent on cardiac output (blood flow) and the oxygen content of arterial blood (hemoglobin and oxygen saturation).
- Hemoglobin is the major contributor of oxygen for tissue demands.

- Normal ventricular filling pressure measurements may not indicate adequate preload volume.
- Measurements of global oxygen balance that may be useful to monitor in the seriously ill patient include central venous oxyhemoglobin saturation ($ScvO_2$) and lactate concentrations.
- Low $ScvO_2$ values suggest an oxygen imbalance that may be the result of decreases in cardiac output, hemoglobin concentrations, or arterial oxyhemoglobin saturation, or increases in tissue oxygen consumption.
- The pulse oximeter estimates arterial oxyhemoglobin saturation but does not reflect adequacy of oxygen delivery.
- Blood pressure monitoring via an arterial catheter is preferable to the use of an automated blood pressure device in unstable patients.
- Determination of systolic blood pressure, pulse pressure, or stroke volume variation and fluid responsiveness using special monitoring devices may be helpful in optimizing cardiac output and oxygen delivery.
- Assessment of acid-base status may suggest specific diagnoses and/or therapeutic interventions.

Suggested Readings

1. Cherpanath T, et al. Predicting fluid responsiveness by passive leg raising: a systematic review and meta-analysis of 23 clinical trials. *Crit Care*. 2016;44(5):981-991.
2. Gauthier PM, Szerlip HM. Metabolic acidosis in the intensive care unit. *Crit Care Clin*. 2002;18:289-308.
3. Hartog C, Bloos F. Venous oxygen saturation. *Best Prac Res Clin Anaesthesiol*. 2014;28:4194-4928.

4. Hernandez G, Ospina-Tascon G, Damiani L, et al. Effect of a resuscitation strategy targeting peripheral perfusion status vs serum lactate levels on 28-day mortality among patients with septic shock. *JAMA*. 2019;321(7):654-664.
5. Jubran A. Pulse oximetry. *Crit Care*. 2015;19:272.
6. Kellum JA. Disorders of acid-base balance. *Crit Care Med*. 2007;35:2630-2636.
7. Kraut JA, Madias NE. Lactic acidosis. *N Engl J Med*. 2014;371:2309-2319.
8. Magder S. Central venous pressure: a useful but not so simple measurement. *Crit Care Med*. 2006;34:2224-2227.
9. Marik PE, Cavallazzi R, Vasu T, Hirani A. Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients. A Systematic review of the literature. *Crit Care Med*. 2009;37:2642-2647.
10. Marx G, Reinhart K. Venous oximetry. *Curr Opin Crit Care*. 2006;12:263-268.
11. Mohammed I, Phillips C. Techniques for determining cardiac output in the intensive care unit. *Crit Care Clin*. 2010;26:355-364.
12. Monnet X, Teboul JL. Assessment of volume responsiveness during mechanical ventilation: recent advances. *Crit Care*. 2013;17:217.
13. Monnet X, Teboul JL. Minimally invasive monitoring. *Crit Care Clin*. 2015;31:25-42.
14. Monnet X, Teboul JL. Passive leg raising. *Intensive Care Med*. 2008;34:659-663.
15. Ortega R, Hansen CJ, Elterman K, et al. Videos in clinical medicine: pulse oximetry. *N Engl J Med*. 2011;3.

16. Whittier WL, Rutecki GW. Primer on clinical acid-base problem solving. *Dis Mon*. 2004;50:122-162.

Chapter 8

DIAGNOSIS AND MANAGEMENT OF SHOCK

Objectives

- Identify the four main categories of shock.
- Discuss the goals of resuscitation in shock.
- Summarize the general principles of shock management.
- Describe the physiologic effects of vasoactive agents.
- Discuss the diagnosis and management of oliguria and acute kidney injury.

Case Study

A 72-year-old man is admitted to the floor with difficulty breathing and a productive cough. His medical history includes chronic obstructive pulmonary disease (COPD), hypertension, and diabetes mellitus. He was prescribed oral antibiotics by his primary care physician 3 days ago. He presented for care with worsening symptoms and was admitted to a medical step-down unit. Now he is unable to speak in complete sentences. Physical examination reveals coarse breath sounds on the left side with scattered wheezes. His skin is cool and clammy. Vital signs include a temperature of 38.8°C (101.8°F), heart rate of 136 beats/min, respiratory rate of 26 breaths/min, blood pressure of 112/40 mm Hg, and pulse oximetry of 84% on 2 L/min of oxygen.

– Is this patient in shock?

– What initial interventions will improve oxygen delivery to his tissues?

– What initial investigations will identify the etiology?

I. INTRODUCTION

Shock is a life-threatening syndrome of impaired tissue oxygenation and perfusion caused by a variety of different etiologies. The diagnosis of shock requires the integration of patient information from the history and physical examination in combination with results from diagnostic studies. Without recognition and treatment, shock may progress to an irreversible state and death. Prompt recognition and early, effective interventions are necessary to prevent organ dysfunction and irreversible organ failure. Efforts to restore adequate perfusion and investigate the cause of shock should occur simultaneously and without delay to minimize morbidity and prevent mortality. Strong evidence supports timely resuscitative efforts to restore perfusion through administration of fluids and vasoactive medications while investigating and correcting the underlying causes of shock.

Impaired tissue oxygenation and perfusion may result from one or more of the following:

- A decrease in systemic oxygen delivery (inadequate cardiac output, low blood oxygen content)
- Ineffective tissue perfusion (maldistribution of blood flow to tissues or inadequate perfusion pressure)
- Impaired use of delivered oxygen (cellular or mitochondrial dysfunction)

The metabolic consequences of cellular hypoxia can be manifested in laboratory studies, such as serum lactate and pH.

II. CLINICAL ALTERATIONS IN SHOCK

The presentation of patients with shock may be subtle (eg, mild confusion, sinus tachycardia) or easily identifiable (profound hypotension, anuria). Shock may be the initial manifestation of an underlying condition or it may develop as the condition progresses.

Providers must be vigilant and prepared to identify shock using clinical assessment and trends in vital signs. ***Tachypnea is a readily apparent compensation and early warning sign of shock***. Clinical manifestations of shock result from inadequate perfusion, compensatory responses, and the specific etiology of shock. Shock that has overwhelmed compensatory mechanisms may present as hypotension, altered mental status, oliguria/anuria, and dysfunction of other organs. A systemic inflammatory response is often triggered by shock and contributes to progression of organ dysfunction and failure.

Direct and indirect effects of hypoperfusion are apparent in laboratory findings, such as abnormalities in blood pH, arterial oxygenation, blood urea nitrogen, creatinine, bilirubin, hepatic transaminases, and coagulation parameters. ***An anion gap metabolic acidosis is a common finding of hypoperfusion and is often associated with an elevated lactate concentration***. An elevated lactate level is a surrogate for systemic hypoperfusion, the severity being reflected by the degree of elevation. Trending lactate levels can be a means to monitor effectiveness of resuscitation.

Compensatory mechanisms in shock involve complex neuroendocrine responses that attempt to increase tissue perfusion and oxygenation. In many forms of shock, sympathetic vasoconstriction redirects blood flow from organs requiring low levels of oxygen (eg, skin) toward oxygen-dependent organs (eg, brain and heart). Compensatory vasoconstriction can maintain blood pressure early in shock and lead to an increase in the diastolic pressure and a narrowing of the pulse pressure. Intense vasoconstriction correlates with cold, clammy extremities and contributes to organ hypoperfusion. Hypothermia also may be a manifestation of severe vasoconstriction. Patients with distributive shock (discussed later) often have vasodilation and warm extremities, but other signs of hypoperfusion are usually present. Tachycardia, mediated by the sympathetic response, reflects an attempt to increase cardiac output in shock. Tachypnea may be a compensatory response to metabolic acidosis, a response to lung injury, or a reaction to direct stimulation of the respiratory center.

> **!**
>
> *The increased systemic vascular resistance present in cardiogenic, hemorrhagic, and obstructive shock reflects compensation to maintain blood pressure (perfusion pressure).*

Additional changes in shock alter oxygenation at the tissue level. As discussed in **Chapter 7**, hemoglobin releases more oxygen as it traverses the capillaries to meet tissue demands. A rightward shift of the oxyhemoglobin saturation curve as a result of acidosis or increased temperature facilitates release of hemoglobin-bound oxygen. The greater extraction of oxygen is reflected in lower mixed venous oxyhemoglobin saturation (SVO_2) or central venous oxyhemoglobin saturation ($ScVO_2$) measurements in many forms of shock (**Chapter 7**). However, a normal value for either of these measurements does not imply that tissue oxygenation is adequate because some forms of shock (eg, septic shock) may lead to impaired tissue or cellular use of oxygen.

III. CLASSIFICATION OF SHOCK

Undifferentiated Shock

Patients presenting in extremis with profound abnormalities in perfusion require rapid interventions to begin correcting their shock state. Because of rapid physiologic deterioration, providers often must begin resuscitative efforts with little to no information as to the etiology of shock. Begin with a primary survey focused on managing life-threatening airway, breathing, and circulation problems, including acute hemorrhage. Effective delegation of tasks among available team members is essential. Definitive interventions are not necessary at first; jaw thrusts and oral/nasal airways can facilitate a patent airway resulting in effective gas exchange and improved breathing. Direct pressure to the site of hemorrhage, use of a tourniquet above the site of hemorrhage, and fluid resuscitation will reduce the loss of hemoglobin and may improve cardiac output.

Obtaining frequent vital signs provides trend information to the resuscitating provider. Initial diagnostics ideally have a short processing time and yield information directly helpful in identifying the etiology of shock. Arterial blood gas (ABG) data with lactate determination quickly provide insight into the perfusion and oxygenation status of the patient. Chest radiographs will identify the presence of an infiltrate, effusion, or pneumothorax contributing to inadequate oxygen delivery. Electrocardiogram (ECG) and telemetry will demonstrate dysrhythmias and morphology changes suggestive of acute ischemia earlier than troponin assays.

Point-of-care ultrasound (POCUS) has emerged as a beneficial tool for the resuscitating provider to identify causes of shock and to assess response to resuscitation efforts; however, specialized training is required for appropriate use.

Classification of Shock Causes

There are four main categories of shock based on causative factors: hypovolemic, distributive, cardiogenic, and obstructive (**Table 8-1**). Each type of shock has unique hemodynamic characteristics. Exacerbation of underlying chronic conditions caused by shock may blur hemodynamic characteristics between the types of shock. Septic shock is a form of distributive shock, but it may have a hypovolemic component before fluid resuscitation. Myocardial dysfunction may be present in septic shock and hypovolemic shock. A careful history and physical examination and focused review of medical records often provide information that is helpful in determining the likely cause of shock.

Table 8-1 Classification of Shock

Hypovolemic	**Cardiogenic**
Hemorrhagic	Ischemic cardiomyopathy (ie, STEMI)
Nonhemorrhagic (ie, burns, GI losses)	Acute valve dysfunction
	Dysrhythmia
Distributive	**Obstructive**
Septic	Massive pulmonary embolism
Adrenal crisis	Tension pneumothorax
Neurogenic (cervicothoracic spinal cord injury)	Cardiac tamponade
Anaphylactic	Constrictive pericarditis
	Abdominal compartment syndrome

Abbreviations: GI, gastrointestinal; STEMI, ST-elevation myocardial infarction.

Knowledge of the expected hemodynamic profiles associated with the different types of shock is helpful in determining appropriate therapy, even when specific measurements are not available. **Table 8-2** presents the usual hemodynamic profiles for more common forms of shock, but variations occur depending on specific etiology, cardiac function, and resuscitation status.

Table 8-2 Hemodynamic Profiles of Shock

Type of Shock	**Heart Rate**	**Cardiac Output**	**Ventricular Filling Pressures (Preload)**	**Systemic Vascular Resistance**	**Pulse Pressure**	**Svo_2 or $Scvo_2$**
Cardiogenic	↑ or ↓[c]	↓	↑	↑	↓	↓
Hypovolemic	↑	↓	↓	↑	↓	↓
Distributive	↑	↑ or N[a]	↓	↓	↑	↑ or N[a]
Obstructive	↑	↓	↑ or N[b]	↑	↓	↓

Abbreviations: SVO_2, mixed venous oxyhemoglobin saturation; $ScVO_2$, central venous oxyhemoglobin saturation; N, normal

[a] May be decreased before or early in resuscitation.

[b] Left ventricular filling pressures may be normal or low in massive pulmonary embolism.

[c] Cardiogenic shock may result from extremes of tachycardia or bradycardia.

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A. Hypovolemic Shock

Hypovolemic shock occurs when intravascular volume is depleted because of hemorrhage, gastrointestinal or urinary fluid losses, dehydration, or profound soft-tissue edema. Internal fluid losses as a result of increased capillary permeability may be prominent in burn injury, trauma, pancreatitis, and other forms of inflammation-associated shock. The hemodynamic findings in hypovolemic shock are decreased cardiac output, decreased right and left ventricular filling pressures (preload), and an increased afterload (systemic vascular resistance [SVR]) caused by compensatory vasoconstriction. The SVO_2 or $ScVO_2$ is decreased because of decreased cardiac output. The value of hemoglobin and hematocrit measurements in acute hemorrhage can be inaccurate because there may not be time for equilibration between fluid compartments to dilute the remaining hemoglobin. An above normal hemoglobin and hematocrit may reflect significant dehydration. Physical examination and correlation with vital signs can direct the provider toward a more complete understanding of hemoglobin and hematocrit measurements. Tachycardia may reflect an attempt to increase cardiac output when stroke volume cannot be increased because of hypovolemia. Capillary refill may be delayed, skin turgor poor, and mucous membranes dry with hypovolemia. POCUS, used by a trained provider, allows identification of hypovolemia by examining the size of the inferior vena cava and response to inspiration. Coaptation of ventricular walls also reflects significant hypovolemia. Internal jugular veins will not distend with the Valsalva maneuver or may be flat on POCUS assessment.

B. Distributive Shock

Loss of peripheral vascular tone (vasodilation) is characteristic of distributive shock. Fluid is sequestered in the venous spaces instead of being returned to the heart. Characteristics of hypovolemic shock and cardiogenic shock are often seen with distributive shock. The most common form of distributive shock is septic shock, with neurogenic shock and anaphylactic shock being much less common. The hemodynamic profile usually includes a normal or increased cardiac output, usually related to low SVR and low to normal ventricular filling pressures. Decreased cardiac output may result if intravascular volume is not optimized or there is co-existing myocardial depression. SVO_2 or $SCVO_2$ may be normal or increased because of shunting of blood in the microvasculature or the inability of tissue to use oxygen (as in sepsis). In contrast to other forms of shock, the vasodilation of fluid-resuscitated distributive shock results in warm extremities, decreased diastolic pressure, and increased pulse pressure. Neurogenic shock caused by cervical or upper thoracic spinal cord dysfunction or injury may be associated with bradycardia rather than tachycardia. Fever may be present in septic shock and adrenal crisis. Close monitoring of the patient with anaphylactic shock for airway compromise is essential because of the risk of rapid development of airway edema.

Anterior myocardial infarction is a common source of cardiogenic shock.

C. Cardiogenic Shock

Ineffective cardiac pump function causing hypoperfusion is the hallmark of cardiogenic shock. Causes include acute valve dysfunction, tachy- and bradydysrhythmias, and acute coronary syndrome. Most patients with cardiogenic shock also have an acute coronary syndrome but other common causes include decompensated heart failure and complications after cardiac surgery. The classic and most common presentation is a low cardiac output or index, elevated SVR, and a high pulmonary capillary wedge pressure, but ventricular preload measurements and SVR can vary depending on the underlying cause. Clinical symptoms include low blood pressure with evidence of end-organ hypoperfusion, such as low urine output, mental status changes, cool extremities along with pulmonary congestion, and a narrowed pulse pressure. POCUS is an excellent resource to identify inadequate pump function, pericardial effusions, and acute valve dysfunction. POCUS also evaluates the effectiveness of fluid resuscitation, vasopressors, and inotropes. Measurement of serum Brain Natriuretic Peptide (BNP) or its fragment molecule, NT-proBNP are useful as diagnostic markers of acute congestive heart failure. Plasma BNP levels in excess of 100 pg/mL are indicative of acute congestive heart failure with high sensitivity and specificity. An NT-proBNP level greater than 900 pg/mL is similarly diagnostic with the same degree of accuracy.

D. Obstructive Shock

The common features in obstructive shock are limitation of cardiac filling because of external compression and excessive afterload. Cardiac tamponade impairs diastolic filling of the right ventricle, whereas tension pneumothorax limits right ventricular filling by obstruction of venous return. Massive pulmonary emboli increase right ventricular afterload and prevent blood from reaching the lungs to be reoxygenated. Severe intra-abdominal hypertension as an element of abdominal compartment syndrome impairs venous return to the heart. Decreased cardiac output, increased afterload, and variable left ventricular filling pressures, depending on the etiology, characterize the hemodynamic profile in obstructive shock. In cardiac tamponade, the pressures of the right heart chambers, the pulmonary artery, and the left heart chambers equilibrate in diastole. A drop of > 10 mm Hg in systolic blood pressure during inspiration (pulsus paradoxus) is an important clinical finding in patients with suspected cardiac tamponade. Distended jugular veins may be seen, depending on the time course of development and intravascular volume status. CT angiography of the chest remains the gold standard for diagnosis of pulmonary embolism. The presence of pericardial effusion with impaired ventricular function on bedside ultrasound is diagnostic for pericardial tamponade. Chest radiography and ultrasound will both be diagnostic of pneumothorax. Tension pneumothorax is diagnosed by a combination of severe hypoxia, absent breath sounds, shock, and a pneumothorax on chest radiograph or absence of pleural slide on bedside ultrasound.

IV. GENERAL PRINCIPLES OF SHOCK MANAGEMENT

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Restoration of hemodynamic stability should be a priority while efforts to treat the cause of shock are implemented.

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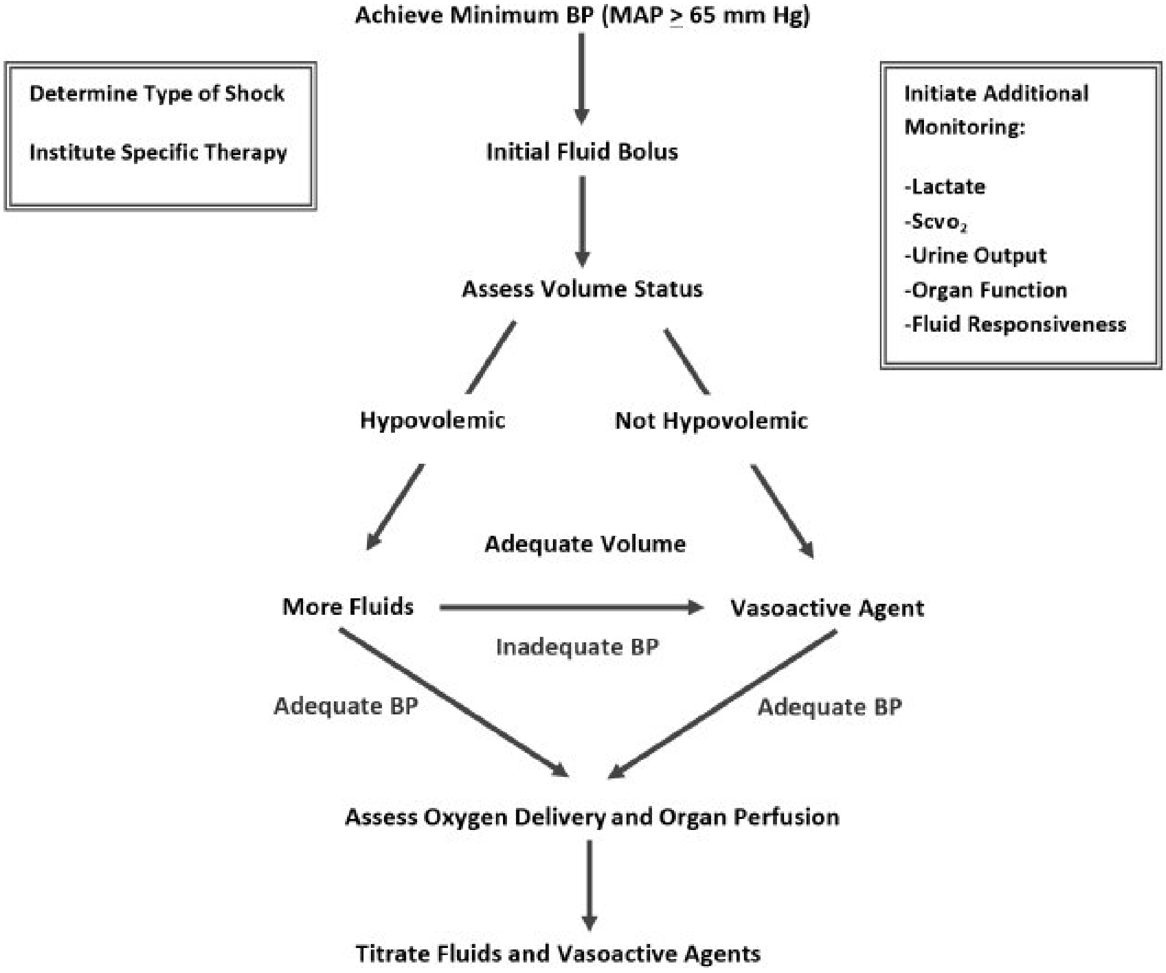
The overall goal of shock management is to improve oxygen delivery and use to prevent cellular and organ injury. Effective therapy requires treatment of the underlying etiology, restoration of adequate perfusion, and comprehensive supportive care. Monitoring should allow for trending and focus on assessing effectiveness of interventions, commonly referred to as "end points of resuscitation." Interventions to restore perfusion center on achieving an adequate blood pressure (typically a mean arterial pressure [MAP] > 65 mm Hg), normalizing cardiac output, and optimizing oxygen delivery. In normal physiology, oxygen delivery far exceeds oxygen consumption, allowing strenuous activity or tolerance of physiologic stress. Oxygen delivery is improved by maximizing saturation of hemoglobin, transfusing red blood cells, and increasing cardiac output (stroke volume × heart rate). Oxygen consumption is increased in severe infection, seizures, and fever. Source control of infections, administration of antipyretics, and control of seizures are effective measures to reduce oxygen consumption. These goals are usually accomplished with a combination of interventions, as summarized in **Table 8-3** and **Figure 8-1**.

Table 8-3 Interventions for Managing Shock

Component	Intervention
Blood pressure	Fluids, vasopressor or vasodilator agents[a]
Cardiac Output	
Preload	Fluids, vasodilator agents[a]
Contractility	Inotropic agents
Afterload	Vasopressor or vasodilator agents[a]
Oxygen Content	
Hemoglobin	Blood transfusion
Hemoglobin saturation	Supplemental oxygenation, mechanical ventilation
Oxygen demand	Mechanical ventilation, sedation, analgesia, antipyretics

[a] Vasodilator agents are used only when blood pressure is adequate.

Figure 8-1. Approach to the Patient With Shock


Achieve Minimum BP (MAP ≥ 65 mm Hg)
Determine Type of Shock
Institute Specific Therapy
Initial Fluid Bolus
Initiate Additional Monitoring:
-Lactate
-Scvo$_2$
-Urine Output
-Organ Function
-Fluid Responsiveness
Assess Volume Status
Hypovolemic
Not Hypovolemic
Adequate Volume
More Fluids
Vasoactive Agent
Inadequate BP
Adequate BP
Adequate BP
Assess Oxygen Delivery and Organ Perfusion
Titrate Fluids and Vasoactive Agents

Abbreviations: BP, blood pressure; MAP, mean arterial pressure
Key aspects of initial shock management include a blood pressure goal, with titration of fluids and vasoactive drugs to ensure adequate intravascular volume and MAP > 65 mm Hg. After these initial objectives are achieved, oxygen delivery and organ perfusion may be assessed by using such monitors as lactate levels, central venous oxygen saturation ($ScVO_2$), urine output, and evidence of end organ performance. Fluid responsiveness may be determined by invasive hemodynamic monitoring systems or simple tests such as straight leg raising.

Shock frequently occurs without hypotension. Providers should not await hypotension to begin treating shock and improving perfusion. Hypotension is a clear sign that compensatory mechanisms are failing and that organs are at risk of progressive failure. The first goal in treating hypotensive shock is to achieve a minimum MAP. This is needed to maintain blood flow to the heart and other organs while optimizing other components of oxygen delivery. A MAP ≥ 65 mm Hg is often recommended as an initial goal. A higher MAP may be needed in patients with myocardial ischemia or chronic hypertension, but an increase in blood pressure is beneficial only if it translates into improved perfusion. Achievement of MAP targets is accomplished with fluid boluses and vasoactive drugs.

It is important to distinguish between achieving blood pressure goals and improving perfusion, which may be exclusive of each other. Blood pressure measurement using noninvasive and invasive methods is far more readily available than newer technologies that measure tissue perfusion. Although normal blood pressure does not necessarily correlate with adequate perfusion, targeting a goal MAP during the early resuscitation of shock is a reasonable initial end point of resuscitation until other markers can be assessed. Caution should be exercised with interventions to improve blood pressure because an associated increase in cardiac output may increase myocardial oxygen demand. Following initial resuscitation, the MAP goal should be individualized based on further assessment of the adequacy of systemic and organ perfusion.

Many patients with shock require intubation.

The next goal in the management of shock is to optimize oxygen delivery. As outlined in **Chapter 7**, this can be enhanced by increasing cardiac output, hemoglobin concentration, or oxyhemoglobin saturation. In the absence of specific measurement of cardiac output or stroke volume, an assessment of adequate oxygen delivery depends on the etiology of shock and the presence of perfusion abnormalities (discussed later). Fluids and/or vasoactive agents are often needed to optimize cardiac output. The determinants of the oxygen content of blood (hemoglobin and oxyhemoglobin saturation) can be easily measured and optimized when indicated. Increasing the hemoglobin concentration by transfusion is an efficient way of improving oxygen delivery by increasing oxygen transport capacity. For example, increasing the hemoglobin concentration from 7 g/dL to 9 g/dL increases oxygen delivery by almost 30%, even if cardiac output remains constant. The oxyhemoglobin saturation can be increased by raising the partial pressure of arterial oxygen with oxygen supplementation and mechanical ventilation. However, once the partial pressure of arterial oxygen has been increased to a range of 60 to 70 mm Hg (8–9.3 k Pa), little additional benefit is gained by increasing it further. An oxyhemoglobin saturation of 95% and greater is recommended in patients with shock.

A. Monitoring

Patients with shock require monitoring to determine appropriate interventions and assess response to interventions (**Chapter 7**). Continuous electrocardiographic monitoring is needed to assess changes in heart rate and rhythm. Blood pressure is best monitored with an arterial catheter because of the inaccuracies of noninvasive devices in patients with shock. Pulse oximetry should be monitored routinely to facilitate assessment of oxyhemoglobin saturation. Hypoperfusion may be disclosed by a poor pulse oximetry waveform. A low central venous pressure in the appropriate clinical situation may suggest inadequate intravascular volume. New technologies assess pulse pressure and stroke volume variation (PPV or SVV) to monitor volume status with greater variability reflecting hypovolemia. Measurement of $ScVO_2$ via a central venous catheter may be useful as an indicator of oxygen balance, but a normal $ScVO_2$ value does not rule out hypoperfusion. Comparison of oxyhemoglobin concentration (O_2Hgb) between venous and arterial blood gases provides insight regarding oxygen delivery and consumption. A urinary catheter should be inserted to monitor urine output as an indicator of renal perfusion, with a suggested goal of 0.5 to 1 mL/kg/h. Lactate concentration and acid-base status should be assessed initially and at appropriate intervals. Normal or decreasing lactate concentrations or improving acidosis suggest improved oxygen delivery and tissue response. Other laboratory data should be considered to assess progression or improvement of organ dysfunction.

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The trend of measurements over time, especially in response to interventions, is often more valuable than a single measurement.

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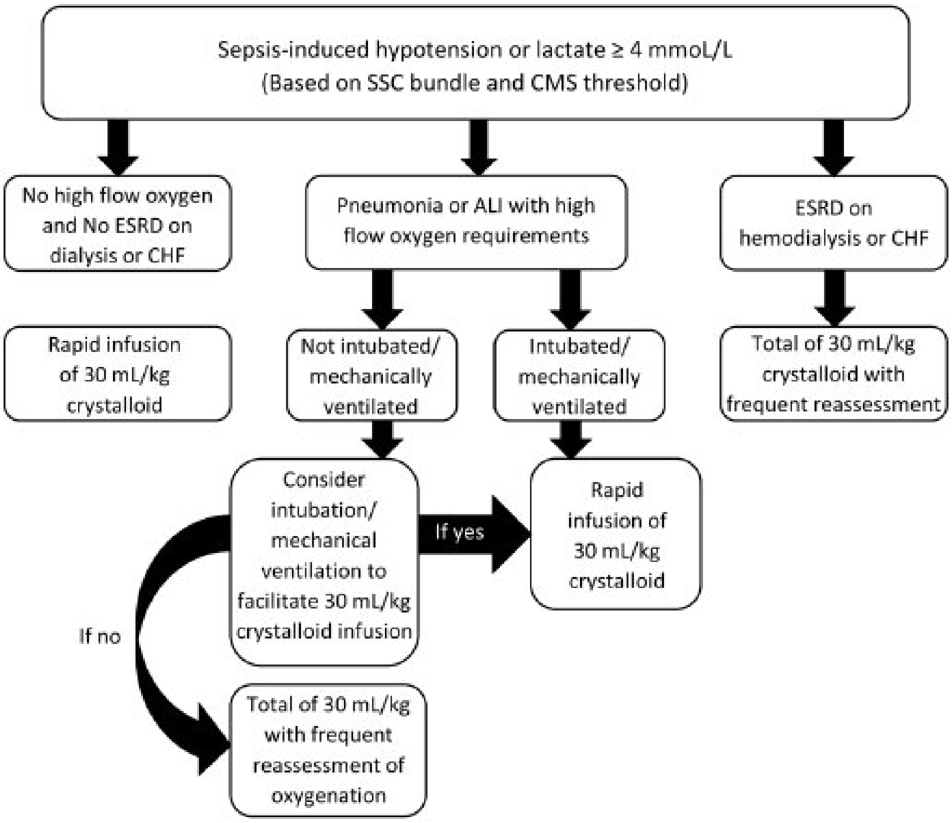
B. Fluid Therapy

Physical examination may provide valuable information about the intravascular volume status. Diffuse or dependent crackles, as well as distended neck veins, suggest high ventricular filling pressures unless acute respiratory distress syndrome or diffuse pneumonia is present. Clear lung fields and flat neck veins suggest inadequate preload in the hypotensive patient. Although orthostatic changes in blood pressure and heart rate may be helpful in determining the degree of volume depletion, the tachycardic hypotensive patient should not be subjected to these positional changes. The nature and degree of fluid deficits should be determined to identify the type and appropriate quantity of fluid replacement. Monitoring of fluid responsiveness, as described in **Chapter 7**, may be helpful in determining the appropriate volume of fluids.

The initial therapy for most forms of shock is expansion of intravascular volume. Increasing preload creates more potential energy by distending the ventricles, resulting in stroke volume increases. It is important to monitor volume status closely to avoid excess preload which reduces cardiac output. Fluid resuscitation in the patient with shock can be more complex in the context of acute and chronic medical conditions. Guidance for fluid resuscitation in adults with septic shock is outlined in **Figure 8.2**. Unless suspicious for hemorrhagic shock, initial fluid resuscitation is begun with either crystalloid or colloid solutions. Crystalloids are less expensive than colloids and typically accomplish the same goals, although a higher total volume is needed because of their higher volume of distribution. Isotonic fluids consisting of a balanced electrolyte solution which closely resemble normal concentrations may avoid iatrogenic metabolic derangements. If 0.9% normal saline is used for fluid resuscitation, providers should monitor electrolytes frequently to avoid iatrogenic hyperchloremia and metabolic acidosis that can occur with infusion of large volumes. Hypotonic fluids may create rapid fluid shifts between intracellular, interstitial, and intravascular spaces as well as severe electrolyte abnormalities. Hypertonic solutions (2%–23.4% saline) should be used with great caution and frequent monitoring of electrolytes. Colloid solutions include hetastarch, albumin, and gelatins. Use of albumin is limited by cost in some areas. Providers should exercise caution in the use of hetastarch for resuscitation of patients in shock because of the increased risk of renal injury and coagulopathy. Crystalloids in titrated boluses of 500 to 1000 mL (up to 30 mL/kg) or colloids in titrated boluses of 250 to 500 mL may be given initially to most adult patients and repeated as necessary while appropriate parameters are closely monitored. Smaller bolus amounts are indicated for patients with suspected or known cardiogenic shock. Use of bedside assessment tools, such as ultrasound and the passive leg raise test, may provide guidance on the benefits and risks of additional fluid. Providers should establish which end points of resuscitation and measurements of volume status will be monitored and evaluate data points regularly.

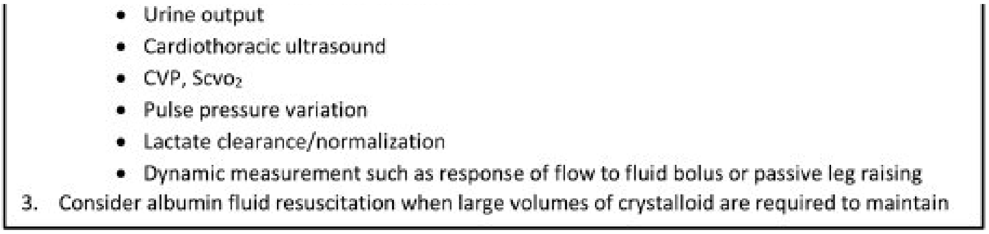
> *Initial administration of 30 mL/kg of crystalloid to adults in septic shock should be followed by reassessments of oxygenation.*

Figure 8-2. Application of Fluid Resuscitation in Adult Septic Shock


Sepsis-induced hypotension or lactate ≥ 4 mmoL/L
(Based on SSC bundle and CMS threshold)
No high flow oxygen and No ESRD on dialysis or CHF
Pneumonia or ALI with high flow oxygen requirements
ESRD on hemodialysis or CHF
Rapid infusion of 30 mL/kg crystalloid
Not intubated/ mechanically ventilated
Intubated/ mechanically ventilated
Total of 30 mL/kg crystalloid with frequent reassessment
Consider intubation/ mechanical ventilation to facilitate 30 mL/kg crystalloid infusion
If yes
Rapid infusion of 30 mL/kg crystalloid
If no
Total of 30 mL/kg with frequent reassessment of oxygenation

Considerations post 30 mL/kg crystalloid infusion

1. Continue to balance fluid resuscitation and vasopressor dose with attention to maintain tissue perfusion and minimize interstitial edema
2. Implement some combination of the list below to aid in further resuscitation choices that may include additional fluid or inotrope therapy
    - Blood pressure/heart rate response



- Urine output
- Cardiothoracic ultrasound
- CVP, Scvo$_2$
- Pulse pressure variation
- Lactate clearance/normalization
- Dynamic measurement such as response of flow to fluid bolus or passive leg raising

3. Consider albumin fluid resuscitation when large volumes of crystalloid are required to maintain

Abbreviations: ALI, acute lung injury; CHF, congestive heart failure; CMS, U.S. Centers for Medicare and Medicaid Services; CVP, central venous pressure; ESRD, end-stage renal disease ; SSC, Surviving Sepsis Campaign; SCVO$_2$, central venous oxygen saturation

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Only red blood cells have oxygen-carrying capacity. Transfusion is appropriate in the setting of acute blood loss anemia (hemorrhagic shock) or among patients with severe impairments in oxygen delivery. In the actively bleeding patient, hemostatic resuscitation with whole blood or a mixture of plasma, platelets, and red blood cells (balanced-ratio component transfusion) is necessary to restore oxygen delivery while simultaneously controlling coagulopathy. Conservative transfusion thresholds (Hgb of 7 g/dL) have been successful in reducing costs without compromising outcomes. Among patients in shock, transfusion should be considered as a means of volume expansion and to improve oxygen delivery. A more liberal approach to transfusion may be relevant in patients with severe hypoxemia, myocardial ischemia, or co-existent hemorrhage who could benefit from increased capacity for oxygen delivery. Correction of coagulopathy among patients in septic shock should be reserved for those with coincidental gastrointestinal bleeding or who are anticoagulated and require reversal for an emergent invasive procedure. Fresh frozen plasma should be used only for correction of a coagulopathy and not for volume replacement. Priorities in the administration of fluids are resuscitation and replacement of ongoing losses. As the clinical course continues, the solution that most closely approximates the patient's losses should be used, with serum electrolytes guiding therapy.

The purpose of achieving euvolemia is to optimize cardiac output and restore perfusion. Often, this correction manifests clinically as resolution of tachycardia, hypotension, or oliguria. However, these end points may remain altered despite euvolemia in states such as septic (distributive), neurogenic, or obstructive shock. Vasoactive drug support is indicated in patients who continue to have a low blood pressure or impaired cardiac output after euvolemia has been established, or who no longer have a beneficial response to fluid challenge or passive leg raising. The potential deleterious effects of overly aggressive fluid resuscitation include deterioration of oxygenation because of pulmonary edema, ileus or bowel edema, and compartment syndromes. Therefore, frequent auscultation of the chest for the presence of crackles, determination of relevant compartment pressures, and monitoring of partial pressure of arterial oxygen or oxyhemoglobin saturation by pulse oximetry should be performed during fluid resuscitation.

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No one vasoactive agent or combination of agents has been demonstrated to be superior in managing shock.

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Intra-abdominal pressure monitoring should be considered in patients requiring massive fluid resuscitation. In the absence of advanced hemodynamic monitoring, volume therapy should be administered carefully in patients with persistent hypotension and/or hypoperfusion until no further change is noted in the blood pressure following a fluid bolus. This suggests that additional fluid no longer improves the patient's cardiac output and administration of more fluid can lead to the deleterious effects noted previously. Further correction of hypotension or other perfusion abnormalities may require pharmacologic support with vasoactive drugs. This approach to volume therapy presents minimal risk in patients with adequate oxygenation.

C. Vasoactive Agents

Vasoactive agents for the acute management of shock include medications with vasopressor, inotropic, and chronotropic effects. A vasopressor is a medication that results in arteriolar constriction, a rise in systemic vascular resistance, and a rise in arterial blood pressure. An inotrope is a medication that augments cardiac contractility. Many agents have more than one hemodynamic effect, and results may vary among individual patients and with dosage. The goals of resuscitation are usually more important than the specific agent chosen. **Table 8-4** summarizes each vasoactive drug and its mechanism of action. An intensivist should be consulted when the decision to use vasoactive medications is made. Early initiation of vasoactive medications is advised to decrease the duration of hypoperfusion.

Guidance for administering vasoactive agents in patient with septic shock is found in **Figure 8.3**. Intraosseous access allows for early administration of vasoactive medications without central venous access. In emergent circumstances, some inotropes and vasopressors can be administered for a short duration through large-bore peripheral IV catheters that are placed at the antecubital fossa or more proximally.

> *Vasoactive agents are important tools to achieve adequate perfusion in shock patients. Steroid administration to address relative or actual adrenal insufficiency may contribute to improved perfusion.*

Table 8-4 Vasoactive Agents

	DA-R (↑UOP)	β_1[a] **(↑HR)**	β_2[b] **(↓BP)**	α_1[c] **(↑BP)**	**V1 Receptors**	**Angiotensin II-type I**[e]
Dopamine 1–20 µg/kg/min	1-5 µg/kg/min	6-10 µg/kg/min		>10 µg/kg/min		
Phenylephrine 1–300 µg/min				+++		
Norepinephrine 0.01–0.5 µg/kg/min (2–30 µg/min)		+		++++		
Epinephrine 0.01–0.5 µg/kg/min (2–50 µg/min)		++++	+++	++++		
Dobutamine (1–20 µg/kg/min)		+++	++			
Milrinone[d] (0.125–0.5 µg/kg/min)		+++	+++			
Vasopressin (0.01–0.04 units/min)					+++	
Angiotensin II (1.25–40 ng/kg/min)						+++

Abbreviations: BP, blood pressure; DA-R, dopamine receptor; HR, heart rate; UOP, urine output Potency scale is from 1+ to 4+

[a] β_1 = adrenergic receptor that increases cardiac contractility and/or heart rate

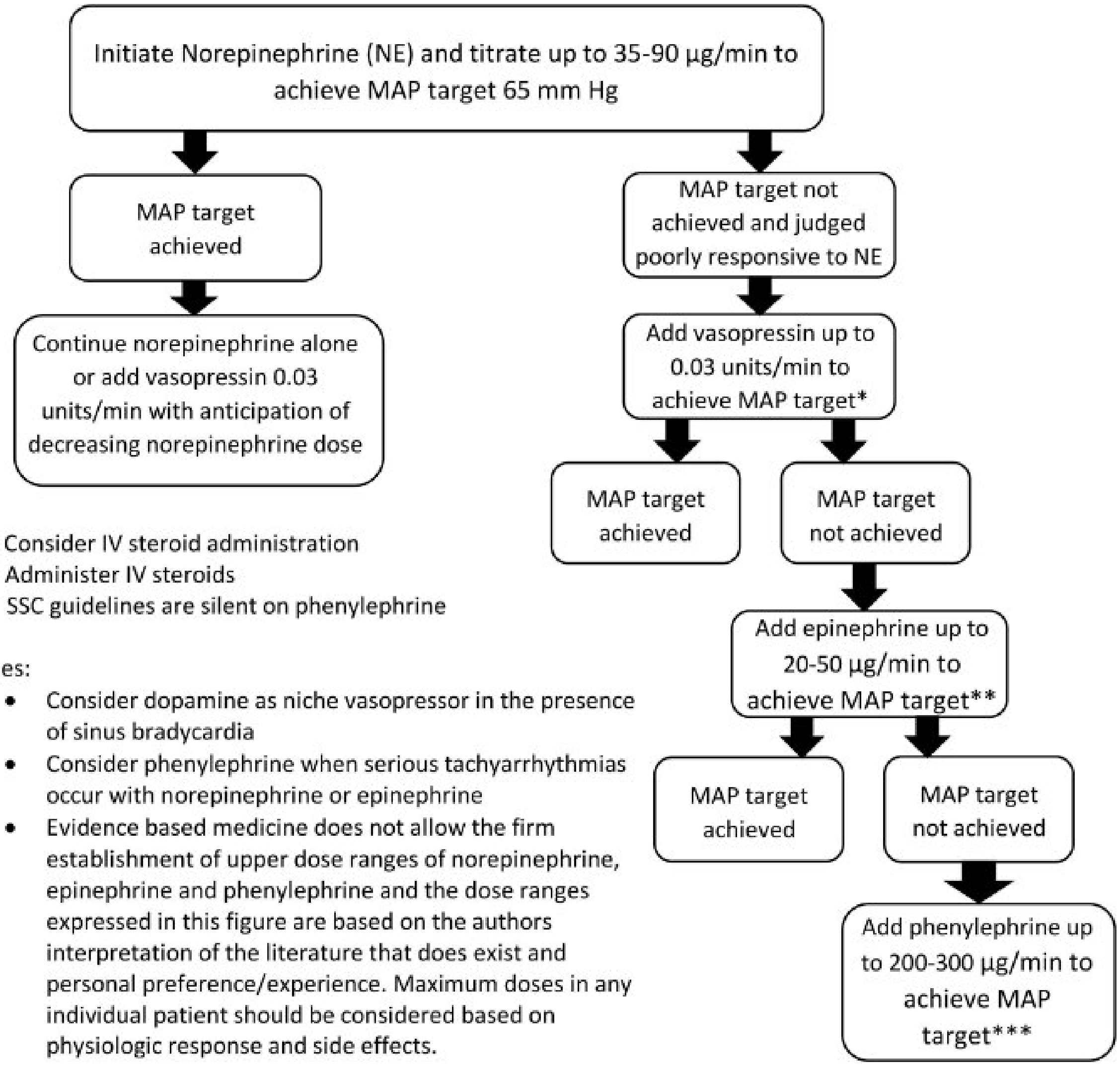
[b] β_2 = adrenergic receptor that mediates bronchodilation and arteriole dilation

[c] α_1 = adrenergic receptor that mediates arteriole constriction and increase in peripheral vascular resistance

[d] Milrinone = a phosphodiesterase inhibitor with indirect β_1 and β_2 effects V1 receptor= vasopressin binds to G-protein-coupled V1 receptors on vascular smooth muscle that leads to increased intracellular calcium levels and vasoconstriction

[e] Ang II-type I = Binds angiotensin II receptor type 1 and stimulates aldosterone release yielding vasoconstriction and increased afterload

Figure 8-3. Vasopressor Use for Adult Septic Shock With Guidance for Steroid Administration


Initiate Norepinephrine (NE) and titrate up to 35-90 μg/min to achieve MAP target 65 mm Hg
MAP target achieved
Continue norepinephrine alone or add vasopressin 0.03 units/min with anticipation of decreasing norepinephrine dose
MAP target not achieved and judged poorly responsive to NE
Add vasopressin up to 0.03 units/min to achieve MAP target*
MAP target achieved
MAP target not achieved
Add epinephrine up to 20-50 μg/min to achieve MAP target**
MAP target achieved
MAP target not achieved
Add phenylephrine up to 200-300 μg/min to achieve MAP target***

* Consider IV steroid administration
** Administer IV steroids
*** SSC guidelines are silent on phenylephrine

Notes:

- Consider dopamine as niche vasopressor in the presence of sinus bradycardia
- Consider phenylephrine when serious tachyarrhythmias occur with norepinephrine or epinephrine
- Evidence based medicine does not allow the firm establishment of upper dose ranges of norepinephrine, epinephrine and phenylephrine and the dose ranges expressed in this figure are based on the authors interpretation of the literature that does exist and personal preference/experience. Maximum doses in any individual patient should be considered based on physiologic response and side effects.

Abbreviation: MAP, mean arterial pressure
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1. Norepinephrine

Norepinephrine is the initial vasoactive drug recommended in the treatment of septic shock. It is a more potent α-adrenergic vasoconstrictor than either dopamine or phenylephrine, and it also has β_1-mediated inotropic and chronotropic effects. In adults, the infusion rate of norepinephrine starts at 0.05 μg/kg/min (μg/min) and is titrated to desired effects. As with other vasoconstrictors, cardiac output may decrease as afterload and blood pressure are increased. Norepinephrine may increase renal blood flow in patients with adequate volume resuscitation. An increase in heart rate is uncommon with use of norepinephrine.

2. Dopamine

Dopamine is a less frequently used vasoactive agent with dose-dependent inotropic and vasopressor effects. It is no longer a drug of choice in the treatment of septic shock. Although dose response varies greatly among patients, some generalizations about dose and anticipated effect may be helpful. At low rates of infusion (1–5 μg/kg/min), dopamine has modest inotropic and chronotropic effects. In this dose range, it acts on the dopaminergic receptors in the kidney and may increase urine output; however, its use for renal effects is not recommended because it does not prevent renal dysfunction or improve outcomes. At intermediate rates of infusion (6–10 μg/kg/min), dopamine has primarily inotropic effects. At higher infusion rates ($\geq$ 10 μg/kg/min), it has significant α-agonist effects that produce dose-related vasoconstriction. At infusion rates $\geq$ 20 μg/kg/min, dopamine usually offers no advantage over norepinephrine, which may have greater vasopressor effect. Potential adverse effects include arrhythmias (particularly atrial fibrillation) and tachycardia.

3. Epinephrine

Epinephrine has both α-adrenergic and β-adrenergic effects, potent inotropic and chronotropic effects, and at higher doses, vasopressor effects. Doses start at 0.05 μg/kg/min (μg/min) and can be titrated as desired. The epinephrine-induced increase in myocardial oxygen consumption may limit the use of this agent in adults, especially in the presence of coronary artery disease. Potential side effects of epinephrine include tachyarrhythmias and increased lactic acid production. The Surviving Sepsis Campaign recommends adding epinephrine as the second-line agent after norepinephrine for patients in septic shock, with a recommended dose of 20–50 μg/min (**Figure 8-3**). Recent literature has also supported the use of "push-dose" epinephrine in the resuscitation of patients with shock who do not have central venous access. This can be especially useful among patients being resuscitated outside of an intensive care unit. Epinephrine 1:10,000 diluted to an epinephrine 10 μg/mL concentration given in 0.5- to 2-mL aliquots every 2 to 5 minutes can facilitate achieving MAP targets while infusions of other vasoactive medications are prepared and intraosseous or central venous access is obtained. Epinephrine is also part of Advanced Cardiac Life Support protocols.

4. Phenylephrine

Phenylephrine is a pure α-adrenergic vasoconstrictor. In adults, the infusion rate starts at 25 μg/min and can be titrated to the desired blood pressure. Because its mechanism of action involves solely arterial constriction, it is most useful in states with arterial dilation without concomitant cardiac depression, such as neurogenic shock or hypotension caused by an epidural anesthetic. Phenylephrine is not recommended for use in septic shock unless in a salvage role when there is failure to improve with multiple other vasoactive medications or significant dysrhythmias occur with norepinephrine. In emergent circumstances, push-dose phenylephrine may be administered via peripheral IV or intraosseous catheter to improve coronary perfusion and cardiac output. Administration consists of 50–200 μg of phenylephrine 100 μg/mL given every 2 to 5 minutes.

5. Vasopressin

Vasopressin is a potent vasopressor that acts through V_1 receptors to produce vasoconstriction. As blood pressure is increased, cardiac output may decrease, similar to the effect of norepinephrine. The recommended dose in adults is 0.01 to 0.04 units/min. In septic shock, vasopressin is recommended by the Surviving Sepsis Guidelines at a fixed dose (0.03 units/min) to augment MAP in patients already on norepinephrine. The addition of vasopressin in septic shock may reduce the dose of norepinephrine needed to achieve MAP targets. Higher doses (0.04 units/min) for prolonged periods of time may lead to ischemic events, especially mesenteric ischemia. Vasopressin may be considered for use in hypotensive shock refractory to other agents and fluid resuscitation, but it has not been found to improve mortality.

6. Dobutamine

Dobutamine is a non-selective β-adrenergic agonist with inotropic effects. It is used in doses of 5 to 20 μg/kg/min and is usually associated with an increase in cardiac output, which is mediated mostly by an increase in stroke volume. Arterial blood pressure may remain unchanged, decrease, or increase slightly. Dobutamine must be introduced with care in the hypotensive patient; in the face of inadequate intravascular volume replacement, blood pressure can drop precipitously and tachycardia may be problematic. This agent has variable chronotropic effects. Among patients in septic shock with concomitant acute heart failure, the inotropic effects of dobutamine may be of value and supersede the use of norepinephrine to achieve MAP targets and improve perfusion.

7. Milrinone

Milrinone is a phosphodiesterase inhibitor that inhibits the breakdown of cyclic adenosine mono-phosphate, the second messenger for catecholamines. Therefore, milrinone is a sympathomimetic agent with mostly β-adrenergic-like effects. It will increase cardiac output mostly by increasing stroke volume and will decrease afterload by causing arteriolar dilation. It should be used with caution in hypovolemic patients because it can cause significant hypotension.

8. Angiotensin II

Angiotensin II is a potent vasoconstrictor and has been recently approved for use by the Food and Drug Administration in high-output shock. Angiotensin II accomplishes this through multiple mechanisms, including direct vasoconstriction of peripheral vessels, water reabsorption through potentiation of antidiuretic hormone, sodium retention via the synthesis of aldosterone, and through synergistic activity with catecholamines. Although it is not a new drug, there is a renewed interest in its use in treating refractory shock. Evidence suggests that angiotensin II may preferentially be of benefit in acute kidney injury and acute respiratory distress syndrome in which the renin-angiotensin system (RAS) is known to be disrupted. During hypotension, the RAS is activated in response to decreased pressure and solute content in the kidney. Acute kidney injury limits the response of the kidney to hypotension. Acute respiratory distress syndrome disrupts the RAS as angiotensin I is converted to angiotensin II in the lungs. Angiotensin II may have a role in cardiogenic shock, angiotensin-converting enzyme inhibitor overdose, cardiac arrest, liver failure, and in settings of extracorporeal circulation. Assessment of a serum renin level may be helpful to determine whether a patient would benefit from this medication.

D. End Points of Resuscitation

No single end point can be used to assess resolution of shock and return to normal homeostasis. Furthermore, fluid and pharmacologic therapy should be titrated based on the trend for the particular end point rather than its absolute value.

Blood pressure, pulse, and urine output are the most commonly used end points in resuscitation of shock. When resuscitating patients with shock early in their course or in facilities with limited resources, easily assessed end points should be used. Achievement of euvolemia may reflect an ability to de-escalate vasopressors and inotropes while maintaining a target MAP. Resolution of metabolic acidosis, normalization of lactic acid levels, and resolution of altered mental status reflect improved perfusion. Insertion of a urinary catheter to monitor urine output should occur early to allow trending. In patients with prolonged hypoperfusion, urine output may remain low despite achieving target blood pressures and improving global perfusion. Urine output may not be a reliable end point in patients with preexisting or new renal dysfunction. All parameters can be easily measured but lack sensitivity and specificity for either detection of impending shock or its resolution. As such, vital signs may be normal even if the patient is in a state of compensated shock. Conversely, vital signs may remain abnormal despite appropriate therapy (eg, low blood pressure and urine output despite reaching a euvolemic state).

In addition to the clinical evaluation of vital signs and urine output, monitoring techniques that assess cardiac output or stroke volume may be helpful in determining when fluid resuscitation is optimized as an end point (**Chapter 7**). Monitoring a PPV or SVV requires arterial catheterization and can be useful beyond the initial resuscitation of patients outside of the intensive care unit. In addition, use of POCUS to assess ventricular filling and inferior vena cava dimensions may be helpful in the assessment of volume status. $ScVO_2$ and lactate concentrations as measurements of global oxygen balance may also be useful in monitoring the patient in shock and assessing the impact of interventions. Neither measurement assesses the need for fluid versus pharmacologic support of the circulation. Normalization of organ function as assessed by laboratory values (such as renal or liver chemistries) is another end point to assess, but these measurements are not usually helpful in the first 24 hours.

V. MANAGEMENT OF SPECIFIC TYPES OF SHOCK

A. Hypovolemic Shock

The treatment goals in hypovolemic shock are restoration of intravascular volume and prevention of further volume loss. Therapy for hypovolemic shock should be targeted to reestablish normal blood pressure, pulse, and organ perfusion. For initial resuscitation, either colloid or crystalloid fluids are effective if given in sufficient volume. Subsequently, the fluid that is used should replace the fluid that has been lost. For example, blood products may be needed to replace blood loss (**Chapter 12**), and crystalloid should be used for vomiting and dehydration. For hypotension, the crystalloid of choice is an isotonic solution because of the osmolality needed to restore intravascular volume. In large volume resuscitation, however, normal saline infusion may produce hyperchloremic metabolic acidosis. Vasoactive medications should be considered only as a temporizing measure while fluid resuscitation is ongoing or when hypotension persists despite adequate volume resuscitation. POCUS allows for ongoing reassessment of volume status and monitoring of response to fluid challenges. Passive leg raise provides an intrinsic bolus equivalent to 300 mL and can demonstrate fluid responsiveness if blood pressure increases by 10–20% after raising both legs to an elevation of 45°. Central venous pressure monitoring may help to guide fluid resuscitation in patients without significant heart or lung disease.

B. Distributive Shock

The initial approach to resuscitating the patient with septic shock, which is a common form of distributive shock, is restoration and maintenance of adequate intravascular volume. Patients with sepsis manifest life-threatening organ dysfunction caused by a dysregulated host response to infection. Prompt recognition is essential in patients with sepsis who have persistent hypotension requiring vasopressors to maintain a MAP of ≥ 65 mm Hg and have a serum lactate level $>$ 2 mmol/L (18 mg/dL) despite adequate volume resuscitation because they have progressed to septic shock. Delays in recognition, resuscitation, antibiotic administration, and achieving other source control are associated with increased morbidity and mortality. Obtaining cultures and prompt administration of appropriate antibiotics are essential, as are other interventions to control the infection (eg, removal of contaminated catheters, surgical procedures including drainage and debridement of infected collections). Culture-proven infection is not necessary to initiate antibiotics; however, cultures are of value later in de-escalating antibiotic therapy. Lactate concentration should be measured and repeated if abnormal as one component of assessing the resuscitation efforts.

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Volume expansion is the initial treatment of septic shock. ***Table 8-4*** *provides a summary of vasoactive drugs that should be added if adequate perfusion is not achieved despite administration of appropriate intravascular volume.*

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Volume expansion should be initiated with isotonic crystalloid solutions with an initial recommended bolus dose of 30 mL/kg and further boluses as needed based on patient response to attain targeted resuscitation goals. Caution should be exercised and lower bolus volumes may be indicated when resuscitating patients with known cardiomyopathy or heart failure. Vasodilation and diffuse capillary leakage are common in septic shock, and fluid requirements may be large. Colloid solutions can be considered for patients who require substantial amounts of crystalloids. If the patient with septic shock remains hypotensive despite adequate fluid resuscitation, norepinephrine is recommended as the initial vasoactive drug. Vasopressin or epinephrine can be considered for patients who fail to respond adequately to norepinephrine. Dobutamine may be considered in those patients with inadequate perfusion after adequate administration of fluids and vasopressors and displaying concomitant heart failure. Reversible myocardial dysfunction with ventricular dilation and a decrease in ejection fraction frequently occurs in shock, especially septic shock. An initial MAP of $<$ 65 mm Hg may require initiation of vasoactive pharmacologic therapy until fluid resuscitation is optimized. Corticosteroids, such as intravenous hydrocortisone in divided doses, may be considered in patients with septic shock when adequate fluids and vasoactive medications fail to restore hemodynamic stability.

Anaphylactic shock is often treated with volume resuscitation and subcutaneous epinephrine. In circumstances of very low blood pressure and poor peripheral perfusion, titrated intravenous vasopressors are indicated. Acute adrenal insufficiency is treated with volume therapy, intravenous corticosteroids, and vasoactive medications, if needed (**Chapter 17**). **Chapter 9** contains information about the management of neurogenic shock.

C. Cardiogenic Shock

The primary goal in treating cardiogenic shock is to improve myocardial function. Arrhythmias should be treated promptly. Reperfusion by percutaneous intervention is the treatment of choice in cardiogenic shock that is the result of myocardial ischemia (**Chapter 15**). Diastolic dysfunction during myocardial ischemia may decrease ventricular compliance and elevate the left ventricular filling pressures, falsely indicating adequate preload. Therefore, a cautious trial of fluid administration may be warranted (250-mL bolus amounts). When blood pressure is decreased in cardiogenic shock, initial therapy with a single agent that has inotropic and vasopressor effects (eg, norepinephrine or dopamine) is indicated. Severely hypotensive patients (systolic arterial pressure < 70 mm Hg) should be treated with norepinephrine to rapidly raise the systolic arterial pressure. The addition of an intravenous inotrope, such as milrinone or dobutamine (or dopexamine, which is available in some countries), may be considered to augment myocardial contractility after blood pressure stabilizes, with the goal of decreasing vasopressor requirements. If moderate hypotension is not responsive to initial therapy, consultation should be sought for potential interventions, such as intra-aortic balloon counterpulsation or left/right ventricular assist devices.

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Afterload and preload reduction should be avoided in cardiac failure when hypotension is present.

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The elevated SVR may impair cardiac output if it is a primary hemodynamic alteration, as occurs in chronic congestive heart failure. Often in acute cardiogenic shock, the SVR is secondarily elevated to maintain vascular perfusion pressure. Treatment aimed primarily at reducing afterload with a vasodilator should be initiated very cautiously and only in patients with hypoperfusion accompanied by adequate blood pressure.

When cardiac failure is characterized by low cardiac output, normal or elevated blood pressure, and hypoxemia caused by high pulmonary capillary pressure, reduction of preload and afterload is helpful in improving hypoxemia. High pulmonary capillary pressure can be diagnosed clinically. Preload reduction is accomplished with loop diuretics (furosemide or bumetanide) and venodilators (nitroglycerin and morphine), whereas afterload reduction is accomplished with arterial vasodilators (angiotensin-converting enzyme inhibitors or, occasionally, nitroprusside). If the blood pressure can be increased to normal levels with inotropes, the cautious addition of afterload and preload reduction is feasible in the presence of low cardiac output or high pulmonary capillary pressure.

D. Obstructive Shock

In the patient with obstructive shock, relief of obstruction is the treatment of choice. Maintenance of intravascular volume is vitally important. Increasing preload by fluid resuscitation may improve the cardiac output and hypotension temporarily. Inotropes or vasopressors have a minimal role in the management of obstructive shock, and these agents provide only temporary improvement, if any. Massive pulmonary embolus is a common cause of obstructive shock.

Treatment for obstructive shock caused by a pulmonary embolism is centered on fluid resuscitation to maintain cardiac output and prompt anticoagulation to prevent clot propagation. Thrombolytic therapy or thrombectomy is sometimes needed in patients with refractory cardiac collapse caused by massive pulmonary emboli. If cardiac tamponade is present, pericardiocentesis may be a lifesaving intervention. Tension pneumothorax must be treated promptly by needle decompression and subsequent tube thoracostomy. Abdominal compartment syndrome in the most extreme cases may require decompressive laparotomy.

> *Diuretics and venodilators should be avoided in obstructive shock.*

VI. OLIGURIA AND ACUTE KIDNEY INJURY

The kidneys are frequently affected by hypotension and hypoperfusion in all forms of shock. Oliguria, defined as urine output < 0.5 mL/kg/h in adults, is an important manifestation of hypoperfusion or decreased glomerular filtration rate. There have been several criteria proposed over the years for consistency in classifying kidney injury. The Kidney Disease Improving Global Outcomes (KDIGO) staging criteria provides a straightforward framework for providers to assess the stage of acute kidney injury based on serum creatinine and urine output criteria. An increase in serum creatinine by (0.3 mg/dL or 1.5-1.9 times baseline) or urine output < 0.5 mL/kg/hr for 6-12 hours are indicative of Stage I Acute Kidney Injury (AKI). Further increases in creatinine and prolonged oliguria or anuria reflect worsening AKI. Additional details regarding advanced stages of AKI can be accessed at https://kdigo.org. Patients with chronic kidney disease or who are regularly dialyzed may be more challenging when assessing for AKI and may best be co-managed with Nephrology. Oliguria may be an earlier indicator of renal dysfunction than changes in laboratory parameters. Persistence of oliguria for at least 6 hours is one criterion for acute kidney injury (AKI). Hypoperfusion may also result in an increase of serum creatinine and blood urea nitrogen, which are the most common laboratory measures of renal function. Acute changes in serum creatinine and urine output are used to define AKI and classify severity across a broad range of renal dysfunction. A key point is that small alterations in creatinine (even a serum creatinine increase of 0.3 mg/dL [26.5 μmol/L] within 48 hours) or urine output predict an increased risk of renal failure and require further evaluation. The preponderance of AKI in the shock patient relates directly to hypovolemia with renal hypoperfusion and development of acute tubular necrosis. Early recognition of hypovolemia and inadequate renal perfusion is essential to facilitate early fluid resuscitation and vasopressor administration to optimize renal perfusion and maintain adequate renal function.

Along with other parameters mentioned previously, resolution of oliguria may be considered a goal of resuscitation in shock. Oliguria also may be the result of inherent renal injury or postrenal obstruction, a situation in which urine output cannot be used as a goal of adequate resuscitation. The degree of oliguria correlates with severity of AKI, with anuria reflecting the most severe cases. Worsening renal laboratory studies should prompt concern and consideration of a nephrology consultation. Maintenance of urine output of at least 0.3 mL/kg/h portends a better prognosis. Causes of oliguria and AKI are categorized as prerenal, renal, and postrenal, as outlined in **Table 8-5**.

Table 8-5 Differential Diagnosis of Oliguria and Acute Kidney Injury

Prerenal

- Decreased cardiac output (eg, volume depletion, cardiac failure, tamponade)
- Redistribution of blood flow (distributive shock) with peripheral vasodilation and/or shunting

Renal

- Glomerular disease (glomerulonephritis)
- Vascular disease (eg, vasculitis)
- Interstitial disease (eg, antibiotics)
- Renal tubular disease
- Ischemia
- Nephrotoxic drugs

Postrenal (Obstructive)

- Bilateral ureteral obstruction
- Urethral stricture
- Bladder outlet obstruction
- Urinary catheter obstruction

Additional laboratory tests may help differentiate prerenal causes of oliguria and AKI from other etiologies. Some laboratory tests of renal function are shown in **Table 8-6**.

Table 8-6 Laboratory Tests to Distinguish Prerenal Conditions from Acute Tubular Necrosis

Laboratory Tests	Prerenal	Acute Tubular Necrosis
Blood urea nitrogen/creatinine ratio	>20	10-20
Urine specific gravity	>1.020	<1.010
Urine osmolality (mOsm/L)	>500	<350
Urinary sodium (mmol/L)	<20	>40
Fractional excretion of sodium (%)[a]	<1	>2

[a] Fractional excretion of sodium = ([urine sodium ÷ serum sodium] ÷ [urine creatinine ÷ serum creatinine]) × 100.

Among patients who have received furosemide recently or chronically, fractional excretion of urea can be measured in place of sodium excretion to assess for prerenal etiologies of AKI and oliguria. Management of oliguria or AKI caused by shock or other etiologies in the critically ill patient should follow an organized approach. The patient should be evaluated promptly to determine the cause of renal dysfunction. Reversible causes should always be rapidly identified and corrected. Insertion of a urinary catheter and a renal ultrasound scan will exclude urinary obstruction in most patients. The urinary catheter is also a useful device to monitor urine output and should be used in patients with shock. More frequent measurements of blood urea nitrogen, serum creatinine, and urine output are needed in the setting of AKI. Volume status should be assessed using clinical examination and the monitoring techniques outlined in **Chapter 7**. Intravascular volume should be optimized with crystalloid and/or colloid solutions to improve renal perfusion. Vasoactive drugs, along with fluids, may be needed in patients with shock to achieve an adequate blood pressure. Loop diuretics may be considered (if blood pressure is adequate) in the setting of volume overload. Although the conversion to a non-oliguric state does not change outcome, fluid management is usually easier with continued urine output, especially in patients with severe hypoxemic respiratory failure. A single dose of furosemide (1–1.5 mg/kg ideal body weight) may be administered as a physiologic stress test in patients without hypotension or active resuscitation. A urine output < 200 mL over 2 hours is a strong predictor of progression to stage III AKI, need for renal replacement therapy, and mortality. No evidence supports the use of low-dose dopamine in oliguric patients. Once oliguric or anuric AKI is confirmed and persistent, fluids should be restricted to the replacement of ongoing losses (including insensible losses). In disease states associated with ongoing loss of intravascular volume, fluid administration is necessary to maintain adequate left ventricular preload. These losses may be substantial, as in pancreatitis, severe sepsis, and large open wounds.

Because there is no specific treatment for most cases of AKI, expectant and supportive care is maintained. Drug dosages need adjustment not only for the severity of AKI but also for the type of renal replacement therapy that may be used. Nephrotoxic drugs (such as intravenous contrast) should be avoided if possible. Monitoring of drug concentrations should be used to guide therapy when possible. Problems with extracellular fluid overload, hyperkalemia, and hypermagnesemia should be anticipated and avoided if possible. Hyperkalemia usually can be managed medically until dialysis is available (**Chapter 17**). Nutritional therapy must be adjusted for renal function and renal replacement therapy.

Renal replacement therapy is necessary when uremic symptoms develop or whenever extracellular volume excess, hyperkalemia (or other electrolyte abnormalities), or metabolic acidosis is refractory to medical therapy. Various intermittent or continuous therapies are available to accomplish fluid removal (ultrafiltration) or solute removal (dialysis, hemofiltration, hemodiafiltration). An appropriate selection depends on the circumstances of the individual patient (especially hemodynamic status) and the resources available. Consultation with a nephrologist is advised to assist with determining the most appropriate treatment.

Case Study Conclusion

A Rapid Response Team assessed the patient and spoke with the on-call hospitalist. An arterial blood gas with lactic acid was obtained to assess adequacy of oxygenation, ventilation, and perfusion. Inhaled bronchodilators were ordered and BiPAP was initiated. A chest radiograph, ECG, and troponin were performed. No evidence of acute coronary syndrome was evident; however, B-lines were present on the chest radiograph and intravenous furosemide was administered. Blood cultures were obtained while the antibiotic spectrum was broadened. Four hours later, the patient was able to oxygenate adequately without BiPAP and was able to speak in complete sentences. His skin is now warm and dry and his vital signs show the following: temperature 37°C (98.6°F), heart rate of 90 beats/min, respiratory rate of 18 breaths/min, blood pressure of 120/80 mm Hg, and SpO_2 of 95% on 2 L/min of oxygen by nasal cannula.

Key Points

Diagnosis and Management of Shock

- Shock is characterized by impaired tissue oxygenation and hypoperfusion.
- The four major categories of shock with characteristic hemodynamic patterns are hypovolemic, distributive, cardiogenic, and obstructive.
- The clinical manifestations of shock result from inadequate tissue oxygenation and perfusion, compensatory responses, and the specific etiology.
- Interventions to restore perfusion center on achieving an adequate blood pressure, increasing cardiac output, optimizing the oxygen content of blood, and/or decreasing oxygen demand.

- The initial therapy for most forms of shock is replacement of intravascular volume with crystalloid or colloid solutions.
- The selection of a vasoactive agent to treat shock should be based on the hemodynamic effect desired for an individual patient and knowledge of the pharmacology of available agents.
- Reversible causes of acute oliguria or AKI should always be excluded, and intravascular volume should be optimized with crystalloid and/or colloid solutions.

Suggested Readings

1. Cecconi M, De Backer D, Antonelli M, et al. Consensus on circulatory shock and hemodynamic monitoring. Task Force of the European Society of Intensive Care Medicine. *Intensive Care Med*. 2014;40(12):1795-1815.
2. Dabrowski GP, Steinberg SM, Ferrara JJ, et al. A critical assessment of endpoints of shock resuscitation. *Surg Clin North Am*. 2000;80(3):825-844.
3. Gutierrez G, Reines HD, Wulf-Gutierrez ME. Clinical review: Hemorrhagic shock. *Crit Care*. 2004;8(5):373-381.
4. Havel C, Arrich J, Losert H, et al. Vasopressors for hypotensive shock. *Cochrane Database Syst Rev*. 2011;(5):CD003709. doi:10.1002/14651858.CD003709.pub3.
5. Kidney Disease: Improving Global Outcomes (KDIGO) Acute Kidney Injury Work Group. KDIGO: Clinical practice guideline for acute kidney injury. *Kidney Int Suppl*. 2012;2:1-138.
6. Koyner JL, Davison DL, Brasha-Mitchell E, et al. Furosemide stress test and biomarkers for the prediction of AKI severity. *J Am Soc Nephrol*. 2015;26(8):2023-2031.
7. Mehta RL, Pascual MT, Soroko S, et al. Spectrum of acute renal failure in the intensive care unit: the PICARD experience. *Kidney Int*. 2004;66(4):1613-1621.

8. Myburgh JA, Mythen MG. Resuscitation fluids. *N Engl J Med*. 2013;369:1243-1251.

9. Oh HJ, Shin DH, Lee MJ, et al. Urine output is associated with prognosis in patients with acute kidney injury requiring continuous renal replacement therapy. *J Crit Care*. 2013;28(4):379-388. doi:10.1016/j.jcrc.2012.11.019

10. Radhakrishnan J, Cattran DC. The KDIGO practice guideline on glomerulonephritis: reading between the (guide)lines--application to the individual patient. *Kidney Int*. 2012;82(8):840-856. doi:10.1038/ki.2012.280

11. Rhodes A, Evans L, Alhazzani W, et al. Surviving Sepsis Campaign: International Guidelines for Management of Sepsis and Septic Shock: 2016. *Crit Care Med*. 2017;45: 1-67. doi:10.1097/CCM.0000000000002255

12. van Diepan S, Katz J, Albert N, et al. Contemporary Management of Cardiogenic Shock: A Scientific Statement. *Circulation*. 2017;136(16):e232-e268. doi:10.1161/CIR.0000000000000525

13. Vincent JL, De Backer D. Circulatory shock. *N Engl J Med*. 2013;369(18):1726-1734.

Suggested Websites

1. Kidney Disease: Improving Global Outcomes. www.kdigo.org.
2. Surviving Sepsis Campaign. www.survivingsepsis.org.
3. Society of Critical Care Medicine. www.SCCM.org.

Chapter 9

NEUROLOGIC SUPPORT

✓ Objectives

- Review the principles of primary and secondary brain insults and the common mechanisms of neuronal injury.
- Apply the concepts of intracranial hypertension and brain oxygen delivery and consumption to the management of the brain-injured patient.
- Review the clinical and diagnostic assessment of a brain-injured patient.
- List common treatments in brain injury.
- Review specific management principles and options for selected pathophysiologic conditions.

Case Study

A 62-year-old man is brought to the emergency department at 6:00 a.m. in the morning after waking up with aphasia and right hemiplegia. He was last seen well the evening before around 11:00 p.m. He has a history of hypertension and type 2 diabetes mellitus. His current medications include aspirin, hydrochlorothiazide, carvedilol, and glyburide. Examination reveals a blood pressure of 160/100 mm Hg, heart rate of 90 beats/min and regular, respiratory rate of 14 breaths/min, and temperature of 37.2°C (98.9°F). He is alert but unable to speak or follow commands. His cranial nerve examination shows a left conjugate gaze preference, absent movement of the right lower face with sparing of the forehead, absence of response to noxious stimuli on the right side of his face, and a diminished gag reflex on the right side. He has a right hemiplegia and does not respond to noxious stimuli applied to the right side of his body. The remainder of his physical examination is unremarkable. An immediate computed tomography (CT) scan of the head shows a small area of decreased grey matter/white matter differentiation in the left insular cortex.

- What type of primary brain injury is likely to be present?
- What is the next important diagnostic test?
- What interventions and monitoring should be instituted in addition to the CT scan?

I. INTRODUCTION

Primary injuries to the brain include ischemic events, trauma, hemorrhage, and anoxia, which may occur either in isolation or in combination. Mechanisms for these and other primary injuries are shown in **Table 9-1**.

Table 9-1 Common Mechanisms of Primary Brain Injuries

- Trauma: concussion, contusion, penetrating injury, and diffuse axonal injury
- Ischemia: global (eg, cardiac arrest with anoxia) or regional (eg, stroke)
- Inflammation: meningitis, encephalitis
- Compression: tumor, cerebral edema, hematoma (eg, epidural, subdural, or intraparenchymal)
- Metabolism: encephalopathies (eg, hepatic, electrolyte, drugs, toxins), prolonged seizures

Often, little can be done to reverse the immediate and frequently devastating effects of the primary cerebral insult that produces neuronal injury or death. In some circumstances, the immediate effects of an injury may be reversed by prompt surgical or medical intervention. Many types of brain insults produce a region of maximum injury associated with a surrounding area of tissue, or penumbra, that may survive and recover if further damage can be mitigated. Common mechanisms of secondary injury are shown in **Table 9-2**. The mechanisms of secondary brain injury may evolve over time from other primary insults. For example, edema after head trauma commonly produces secondary brain compression, vasospasm after subarachnoid hemorrhage (SAH) may cause regional ischemia and stroke, or secondary hemorrhagic conversion after an ischemic stroke may induce compression and further ischemia.

Table 9-2 Common Mechanisms of Secondary Brain Injuries

- Hypoperfusion: global (eg, secondary to high intracranial pressure, systemic arterial hypotension, or severe anemia) or regional (eg, secondary to high intracranial pressure, local edema, or vasospasm)
- Hypoxia: systemic hypoxemia, regional hypoperfusion, or high tissue consumption (ie, seizures, hyperthermia)
- Electrolyte or acid-base changes from systemic or regional ischemia
- Reperfusion injury with inflammation and free radical formation
- Prolonged seizures

II. BRAIN INJURY MANAGEMENT PRINCIPLES

Because the primary injury in the central nervous system is often not reversible, the main goal for treatment is prevention of secondary injury. The focus of treatment for a neurologically compromised patient is the same as the one aimed for patients with other illnesses and injuries, that is, to ensure adequate oxygen delivery to meet the needs of both the damaged and the undamaged brain tissue. The initial care team must take early and aggressive action to ensure that secondary brain injury is prevented, minimized, or reversed with careful monitoring and management, particularly the prevention and early treatment of hypoxia and hypotension. Optimizing oxygen delivery to the brain requires attention to oxygenation, hemoglobin concentration, cardiac output, and blood pressure (BP). Prevention and early treatment of fever, pain, agitation, and anxiety can minimize oxygen demands. A unique challenge in acute brain injury is the metabolic demand caused by seizures which can potentiate secondary injury. Therefore, monitoring and treatment of seizures is an important aspect of preventing secondary injury.

A. Intracranial Hypertension

Intracranial pressure (ICP) reflects the balance of volume-control mechanisms within the noncompliant cranial compartment. Because the brain is enclosed within the rigid skull and relatively inflexible dura, with tissues and fluids that are not compressible, control of the different intracranial components is essential to maintain brain homeostasis, regulate ICP, and preserve cerebral perfusion. The critical compartment relationship depends on the volume occupied by each component. An increase in one component (eg, brain) must be accompanied by a decrease in another component (eg, blood), also known as the Monro-Kellie doctrine. When the compensatory mechanisms are overwhelmed, ICP increases and injury may ensue. In addition to the impaired cerebral perfusion, which may be a consequence of globally increased ICP, small pressure gradients within the skull may cause herniation of the brain around dural reflections (the falx and the tentorium), with shift of the midline structures. These movements within the skull may compromise function (eg, cause stupor or coma by disrupting the activity of the brainstem reticular formation) or lead to vascular compression and stroke. Understanding the vector of intercompartmental shifts in the cranium can help predict which patients will experience life-threatening secondary injury from compression.

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Increased ICP has an important effect on the regional and global supplies of oxygen to the brain because it compresses arteries and decreases cerebral blood flow.

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An intensivist, neurointensivist, or a neurosurgeon should be consulted if intracranial hypertension is suspected. The patient may need ICP monitoring either through a catheter inserted into a lateral ventricle (allows both monitoring and drainage of cerebrospinal fluid [CSF]), or a strain gauge (or fiberoptic) pressure monitor inserted into the brain parenchyma (**Table 9-3**). This monitoring includes ICP, temperature, and/or brain oxygen. Measurements of cerebral oxygenation require special equipment and expertise that are not available in most facilities. When direct measures are not available, the initial care team must treat the patient based on the principles of oxygen supply and demand.

Table 9-3 Conditions Potentially Requiring Invasive Intracranial Pressure Monitoring

- Traumatic brain injury (**Table 9-6**)
- Acute obstructive hydrocephalus from acute subarachnoid hemorrhage, intracranial hemorrhage with intraventricular extension, or cerebellar stroke or hemorrhage compressing the fourth ventricle
- Nonobstructive hydrocephalus from subarachnoid/intraventricular hemorrhage or infection/inflammation in the meninges
- Subarachnoid hemorrhage with coma or clinical deterioration if increased ICP is suspected
- Large ischemic stroke
- Fulminant hepatic failure
- Global brain ischemia/anoxia with increasing edema

B. Impaired Substrate Delivery (Hypoperfusion and Hypoxia)

Cerebral autoregulation reflects an active and passive system of blood flow physiology by which arteriolar dilation or constriction controls regional cerebral blood flow (CBF) and links oxygen demand to its delivery. Thus, global CBF normally remains constant over a defined range of mean arterial pressures (MAP). Loss of autoregulation occurs in many pathologic conditions and may lead to regional or global vasodilation and edema formation that can further increase ICP. Increases in blood volume also profoundly affect the pressure inside the noncompliant cranial vault (based on the Monro-Kellie doctrine).

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> *Although related, changes in CPP may not always result in similar changes in CBF.*
> !

CBF correlates with the cerebral perfusion pressure (CPP) in many pathologic conditions in which autoregulation is impaired. CPP is defined as the MAP minus the ICP (the pressure impeding blood flow):

$$\text{CPP} = \text{MAP} - \text{ICP}$$

The normal CPP is between 60 and 100 mm Hg. If the ICP increases without a change in MAP, CPP decreases, and CBF will also decrease if autoregulation has failed. The decrease in CBF increases the risk of brain ischemia. Clinicians should pay particular attention to changes in mental status because these may indicate inadequate perfusion (among many other possibilities).

The MAP must be measured at the same location as the ICP to be accurate; this is usually done by zeroing the arterial line transducer at the ear and keeping it at the same height as the head when the head is elevated. It is important to understand that the correlation between CBF and CPP assumes normal cardiac output. Impaired cardiac output, particularly when associated with strong vasoconstrictor medications (vasopressors), will dissociate CPP and CBF.

C. Recommendations for Therapy

Therapy for acute brain injury is based on the two previously mentioned physiologies: reduction of intracranial hypertension and optimization of substrate delivery. Algorithmic management of ICP after brain injury is an important mechanism to standardize care. The typical progression includes the use of osmotic agents, such as mannitol and hypertonic fluids, to increase the oncotic pressure in the blood and draw interstitial fluid out of the brain, thereby decreasing “brain water.” Further management techniques include diverting CSF through an external ventricular device, upright body positioning to optimize CSF transit out of the calvarium, and prevention of events that increase sympathetic tone, such as seizures.

In parallel to pressure-reducing therapies, strategies to minimize damage to the brain in distress focus on therapies designed to balance oxygen demand and substrate delivery (CBF and oxygen). **Table 9-4** summarizes commonly accepted principles and therapeutic guidelines for treating a variety of brain insults and avoiding secondary brain injury. Note the focus on factors that minimize oxygen consumption and maximize oxygen delivery.

Table 9-4 General Principles of Managing Brain Injury

Prevent Abnormal Oxygen Demands

1. Avoid fever. Fever increases metabolic demand, resulting in neuronal injury and elevates ICP.
2. Avoid seizures. Prophylactic anticonvulsant administration is indicated after moderate or severe traumatic brain injury to prevent seizures in the first week, but the available evidence does not support longer use in head trauma or its use in other neurologic injuries.
3. Avoid anxiety, agitation, or pain. Neuronal oxygen consumption may be decreased by an antianxiety agent, sedation, and analgesia.
4. Avoid shivering.
5. Minimize stimulation, particularly for the first 72 hours.

Promote Oxygen Delivery

1. Ensure systemic oxygen transport with adequate oxygenation, hemoglobin concentration, and cardiac output.
2. Ensure optimal BP. Many primary insults are associated with hypertension that may be a physiologic compensation or may be injurious. Elevated BP may be undesirable in patients with unsecured aneurysms and recent intracranial hemorrhage. *However, excessive lowering of BP may result in secondary ischemia.*
3. Avoid prophylactic or routine hyperventilation because an increase in extracellular brain pH constricts responsive vessels and may reduce CBF to ischemic zones. Brief hyperventilation while instituting other methods to lower elevated ICP may be lifesaving in patients with evidence of herniation.
4. Ensure euvolemia because hypovolemia may result in systemic hypotension and hypoperfusion of brain tissue.
5. Rapid sequence intubation should be used for patients with increased ICP. Consider administration of intravenous lidocaine or intravenous propofol to blunt the rise in the ICP associated with intubation. Avoid using depolarizing neuromuscular blockers (ie, succinylcholine) without defasciculating doses of nondepolarizing blockers (ie, vecuronium, rocuronium, and cisatracurium).

III. ASSESSMENT

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Early identification of patients with ischemic stroke or potential surgical lesions provides the *best opportunity to minimize secondary brain injury.*

After appropriate management of airway, breathing, and hemodynamic concerns, the priority in neurologic assessment is to distinguish among ischemic, structural, metabolic, and infectious injuries. Suspected ischemic stroke requires an immediate decision regarding thrombolytic therapy or intervention, and emergent neurologic consultation should be obtained. The presence of an expanding mass lesion accompanied by significant brain shift may indicate the need for immediate surgical evaluation and possible intervention. The most common causes of such an event include epidural, subdural, and intracerebral hematomas. Intracranial hematomas should be suspected in the settings of head trauma, recent neurosurgery, anticoagulant therapy, alcohol abuse, coagulopathies, and chronic or acute hypertension. The diagnostic procedure of choice, CT scan of the brain, characterizes the extent of structural injury. Medical treatment may be a temporizing option until more definitive therapy is available and implemented.

Serial examinations are necessary to detect the possible sequelae of many brain insults. Any change in the examination is an indicator of deterioration and should prompt an immediate and thorough reevaluation. For example, decreased consciousness without lateralizing findings may be the result of elevated ICP, hydrocephalus, fever, toxic substances, or worsening of an encephalopathy, etc.

The Glasgow Coma Scale (GCS) score is widely used in the initial and serial assessment of patients with head trauma, and it may be useful in evaluating patients with other brain insults. Importantly, it serves as a standardized language by which the care team can communicate the level of responsiveness of the patient. **Table 9-5** lists its components.

When physical examination or CT scan suggests significant brain compression, medical therapy to *reduce ICP should be instituted immediately while awaiting definitive treatment.*

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Serial examinations, including evaluation of brainstem and cranial nerve function, should be performed. Pupillary asymmetry may be an important sign of unilateral compression with midline shift, which commonly precedes downward herniation in patients with supratentorial masses. Uncoordinated eye movements, a change in respiratory pattern, or deterioration in motor response may suggest an increase in intracranial mass effect and should be investigated immediately.

Table 9-5 Components of Glasgow Coma Scale Score

Clinical Parameters	Adults	Points
Eye opening	Spontaneous	4
	Response to speech	3
	Response to pain	2
	No response	1
Verbal response	Oriented and appropriate	5
	Disoriented and confused	4
	Inappropriate words	3
	Incomprehensible sounds	2
	No response	1
Best motor response	Obeys commands	6
	Localizes	5
	Withdraws from pain	4
	Flexor response	3
	Extensor response	2
	No response	1

Total Glasgow Coma Scale score = eye + verbal + motor scores; best possible score = 15, worst possible score = 3

The Cushing reflex of hypertension followed by bradycardia and altered respiration may indicate downward central brain herniation.

When clinical findings suggest downward central herniation, emergent administration of mannitol or hypertonic saline should be initiated to lower ICP, and emergent neurosurgical assistance should be obtained. A brief period of hyperventilation may be considered with the understanding that hyperventilation has been found to increase brain ischemia and should be used only as a temporizing measure when the patient's survival is in question. Whether repetition of an imaging study or immediate surgical therapy is required depends on the nature, location, and progression of the pathologic process.

Neurosurgical consultation is advised for any patient who: (1) is at risk for developing an expanding intracranial mass lesion; (2) has an open or depressed skull fracture or acute ventricular obstruction; (3) demonstrates blood in the fourth ventricle, cerebellar bleeding, or SAH; or (4) has CSF leakage. Nontraumatic disease processes, such as spontaneous intracerebral hematoma, large brain tumors, or brain abscesses, require urgent neurosurgical consultation if clinical findings or an imaging study indicate significant mass effect (midline deviation, ventricular obliteration, brainstem or basal cistern compression).

Urgent neurosurgical consultation should be obtained for hemorrhages and infarcts in the posterior fossa regardless of the level of consciousness. Although such patients may have few findings on initial clinical examination, progressive swelling around the lesion may necessitate emergent surgical decompression. Typically, any cerebellar mass greater than 3 cm in diameter with hydrocephalus or brainstem compression requires consideration of evacuation.

IV. SPECIFIC DIAGNOSES AND CONSIDERATIONS

A. Traumatic Brain Injury

Approximately 25% of patients who experience blunt head trauma require urgent evacuation of a subdural hematoma (**Figure 9-1A**) or an epidural hematoma (**Figure 9-1B**) to relieve compression of the brain. Neurosurgical consultation should be considered early. Because 20% of patients with severe traumatic brain injury (TBI) will have concomitant cervical spinal cord injuries, immobilization of the cervical spine until it can be appropriately assessed is very important.

Figure 9-1A. Subdural Hematoma

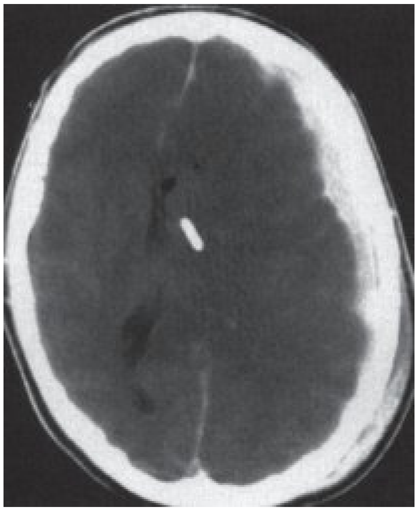
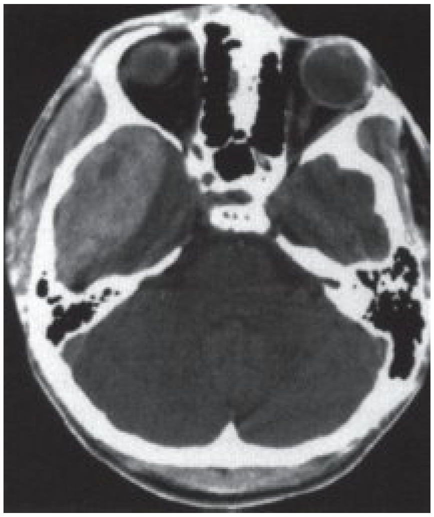


Figure 9-1B. Epidural Hematoma



Cerebellar hemorrhage with altered consciousness is a surgical emergency.

Penetrating and nonpenetrating head injuries are often associated with the formation of cerebral edema, brain contusions, or hemorrhage within the parenchyma. Because the skull cannot expand to accommodate increased intracranial volume and the compensatory space in the subarachnoid space of the spinal canal is very limited, the ICP commonly becomes elevated. Monitoring and treatment of increased ICP are considered important in such patients.

Guidelines for the management of severe TBI have been developed by the Brain Trauma Foundation on the basis of established evidence and expert opinion. These principles are included in the recommendations in **Table 9-6**.

Table 9-6 General Principles for Treatment of Traumatic Brain Injury

- Ensure the ABCs of resuscitation are performed.
- Avoid hypotension and maintain systolic BP ≥100 mm Hg for patients 50–69 years old or ≥110 mm Hg for patients 15–49 or >70 years old. Optimal mean arterial pressure is unknown.
- Avoid hypoxemia (Pa_{O_2} <60 mm Hg [8.0 kPa] or oxygen saturation <90%) while adequate oxygenation is maintained.
- Maintain alignment between head and trunk to avoid jugular compression.
- Keep the head of the bed at 30° to 45° elevation unless the patient is hypotensive. Elevation of the head promotes venous drainage and CSF displacement to the spinal compartment. Adjust any devices that may constrict the neck, including cervical collars.
- Treating sustained ICP >22 mm Hg is recommended because values above this level are associated with increased mortality. A combination of ICP values, clinical examination, and brain CT findings may be used to make management decisions.
- Maintain the Pa_{CO_2} at 35 to 40 mm Hg (4.7–5.3 kPa). Prolonged prophylactic hyperventilation with a partial pressure of carbon dioxide in arterial blood (Pa_{CO_2}) of 25 mm Hg or less is **NOT** recommended.
- Use normal saline as the primary maintenance fluid. Do not use hypotonic fluids.
- Actively treat fever to maintain body temperature at normal levels.
- Prophylactic hypothermia within 2.5 hours and within 48 hours post-injury is **NOT** recommended to improve outcomes in patients with diffuse injury.
- Control agitation with sedation if necessary. Use medications with a relatively short half-life to facilitate reliable and ongoing neurologic assessments.
- Maintain electrolyte homeostasis and treat hyperglycemia/hypoglycemia.
- Assess and treat coagulation defects.
- Low-molecular-weight heparin or low-dose unfractionated heparin may be used in combination with mechanical prophylaxis. However, there is an increased risk of intracranial hemorrhage.
- Provide nutrition to attain full caloric replacements as tolerated by at least the fifth day and at most by the seventh day post-injury to reduce mortality. Post-duodenal feeding is recommended to reduce the incidence of ventilator-associated pneumonia.
- Prophylactic use of phenytoin or valproate is **NOT** recommended for prevention of late posttraumatic seizures (PTS). However, phenytoin is recommended to decrease the prevalence of early PTS within 7 days of a TBI when the benefit outweighs the risk of complications associated with this treatment, although early PTS have not been associated with worse outcomes. (There is insufficient evidence to recommend levetiracetam when compared with phenytoin in preventing early PTS and toxicity at this time).
- Although hyperosmolar therapy may lower ICP, there is insufficient evidence to support the use of any specific hyperosmolar agent to lower ICP for patients with severe TBI.
- AVOID steroid use. These agents are contraindicated in patients with head trauma because they are associated with increased mortality.
- Management of patients with severe TBI using information from ICP monitoring is recommended to reduce in-hospital and 2-week post-injury mortality.
- The recommended target CPP value for survival and favorable outcomes is between 60 and 70 mm Hg. Whether 60 or 70 mm Hg is the minimum optimal CPP threshold is unclear and may depend on the patient's autoregulatory status. Aggressive attempts to maintain CPP >70 mm Hg with fluids and/or vasopressors may be avoided because of the risk of adult respiratory failure or other adverse effects.
- Bifrontal decompressive craniotomy (DC) is **NOT** recommended to improve outcomes in patients with severe TBI with diffuse injury and with ICP elevation to values >20 mm Hg for more than 15 minutes within a 1-hour period that are refractory to first-tier therapies. However, it has been demonstrated to reduce ICP and to minimize days in the ICU.
- A large fronto-temporoparietal DC is recommended over a small one for reduced mortality and improved neurologic outcomes in patients with severe TBI.
- An external ventricular device (EVD) zeroed at the midbrain with continuous drainage of CSF may be considered to lower ICP more effectively than intermittent use. Use of CSF drainage to lower ICP in patients with an initial GCS score of <6 during the first 12 hours after injury may be considered.

- Administration of barbiturates to induce burst suppression measured by EEG as prophylaxis against the development of intracranial hypertension is **NOT** recommended.
- High-dose barbiturate administration is recommended to control elevated ICP refractory to maximum standard medical and surgical treatment. Hemodynamic stability is essential before and during barbiturate therapy.
- Although propofol is recommended for the control of ICP, it is **NOT** recommended for improved mortality or 6-month outcomes. Caution is required because high-dose propofol can produce significant morbidity.
- Jugular bulb monitoring of arteriovenous oxygen content difference as a source of information for management decisions may be considered to reduce mortality and to improve outcomes at 3 and 6 months after injury. Avoid jugular venous saturation of <50% in order to reduce mortality and improve outcomes.

Abbreviations: CPP, cerebral perfusion pressure; CSF, cerebral spinal fluid; CT, computed tomography; DC, depressive craniectomy; EVD, external ventricular device; GCS, Glasgow Coma Scale; ICP, intracranial pressure; PTS, posttraumatic seizures; TBI, traumatic brain injury.

B. Intracerebral Hemorrhage

Intracerebral hemorrhage (ICH) occurs in 12 to 31 per 100,000 people each year in the United States, accounting for 10% of all strokes. Approximately 60% of patients with ICH have a history of hypertension. Other frequent causes include cerebral amyloid angiopathy (CAA), coagulopathy, medication-induced, vascular abnormalities, and sympathomimetic drugs.

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Intracerebral hemorrhage (ICH) mortality increases as ICH score increases. An ICH score 3 has a mortality of 72% and reaches 100% with an ICH score 5 & 6.

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ICH is a medical emergency. Rapid diagnosis and management are crucial because early deterioration is common in the first few hours after the onset of ICH. It is important for the clinician to assess the need for airway support, the risk of herniation and brainstem compression, hematoma expansion, elevated ICP, and strategies for prevention of secondary brain injury. A contrast-enhanced CT scan can occasionally show a “spot sign” (a contrast spot in the hemorrhage bed) that suggests continued bleeding. The clinician should also calculate the ICH score, a grading scale composed of GCS score, age, and initial neuroimaging. It predicts in-hospital mortality and is useful in counseling families.

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Rapid diagnosis and management is crucial because early deterioration is common in the first few hours after the onset of ICH.

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Elevated BP may contribute to rebleeding and edema formation but may also preserve regional CPP. Recent guidelines suggest target BP control (systolic blood pressure [SBP] 140–180 mm Hg) with the understanding that patients with long-standing hypertension and history of chronic kidney disease are at higher risk of acute kidney injury. Basic principles of BP control include rapid correction with titratable agents. If elevated ICP is suspected, expert consultation is advised for assistance with BP management. Preferred agents include labetalol, nicardipine, or clevidipine. Use of vasodilators remains controversial, but medications that cause substantial intracranial vasodilation (eg, nitroprusside, nitroglycerin) should be avoided.

Expansion of the hematoma occurs commonly, especially in patients taking anticoagulants or antiplatelet agents, have liver disease, have platelet dysfunction related to end-stage renal disease, or have a low platelet count. Rapid reversal of coagulopathy with appropriate reversal agents should be done as soon as possible. Neurosurgical consultation for evacuation of hematoma should be considered in patients with a life-threatening deteriorating neurologic examination, cerebellar location, intraventricular hemorrhage causing hydrocephalus, and large mass effect. Some neurosurgeons may consider removal of the hematoma, especially in a young, clinically deteriorating patient with a large lobar hemorrhage or when the hemorrhage is associated with a surgically treatable lesion, such as an aneurysm, arteriovenous malformation, or cavernous angioma. Deep basal ganglionic hemorrhages do not yet have a universally accepted surgical therapy (**Figure 9-2A**). Small hemorrhages may not require specific surgical therapy (**Figure 9-2B**).

Figure 9-2A. CT Scan Demonstrating Large Right Basal Ganglion Intracerebral Hemorrhage with Midline Shift and Intraventricular Extension

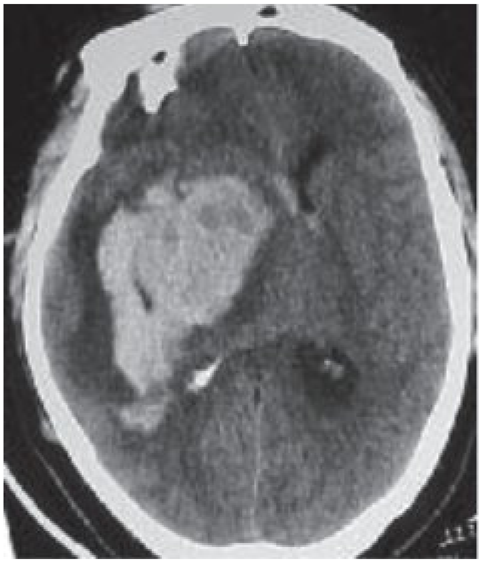
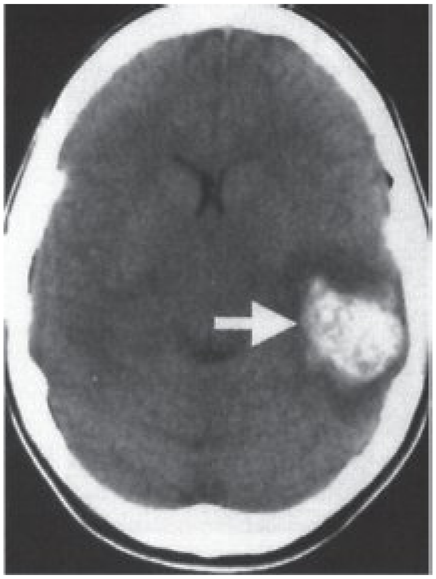


Figure 9-2B. CT Scan Demonstrating Small Left Parietal Lobar Intracerebral Hemorrhage



C. Subarachnoid Hemorrhage

Subarachnoid hemorrhage may be categorized as traumatic or nontraumatic. Nontraumatic SAH, often aneurysmal in nature, accounts for 1% to 7% of all strokes and is considered a neurovascular emergency. Overall, approximately 10% of patients die before arriving at the hospital and 65% of survivors are left with some cognitive impairment. Therefore, prompt consultation with a center experienced in the care of these patients is advised. Characteristics from the patient history ("worst headache of their life") and CT findings usually confirm the diagnosis of SAH (**Figure 9-3**). Classification systems (eg, the Hunt and Hess scale or the Fisher scale) have been used to categorize findings and suggest prognosis but do not alter the care provided by the primary team, as outlined in **Table 9-7**. The treatment plan should include securing the aneurysm before the period of delayed deterioration (within first 24 hours has become a common standard) to prevent rebleeding, diagnose and manage obstructive hydrocephalus, and monitor for and treat delayed neurologic deterioration (cerebral vasospasm), including vasospasm prophylaxis with nimodipine within 24 hours. Nimodipine is beneficial because it can reduce the possibility of secondary cerebral hemorrhage, has neuroprotective properties, and improves overall outcomes. Guidelines are available from the American Heart Association/American Stroke Association (AHA/ASA) and the Neurocritical Care Society. Almost all patients, regardless of severity, should be stabilized and evaluated for rapid transfer to a specialized center for management.

Figure 9-3. CT Scan Demonstrating Subarachnoid Hemorrhage (FCCS 6th ed Figure 9-3)

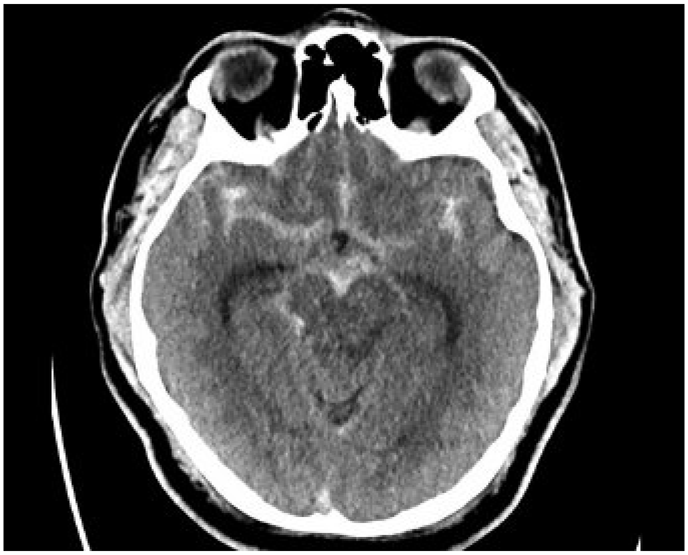


Table 9-7	Treatment of Subarachnoid Hemorrhage

- Ensure the ABCs of resuscitation are performed.
- Perform rapid evaluation of the aneurysm location for surgical clipping or coiling, which requires urgent neurosurgical and/or neurointerventional consultation.
- Hydrocephalus is caused by blockage of CSF circulation and absorption. Temporary CSF diversion is achieved with an EVD.
- Control BP early, before definitive surgical therapy. The standard is to keep SBP >140 mm Hg (with concern for patients with preexisting hypertension and/or chronic kidney disease). Rebleeding is the major early complication until the aneurysm is clipped or coiled. A variety of intravenous agents have been useful. Labetalol and nicardipine have been advocated. Nitroprusside should be avoided because of its tendency to induce cerebral vasodilation. Nimodipine, a calcium channel blocker used to treat delayed deterioration, can have effects on BP that can be amplified when using other antihypertensive agents.
- Initiate oral nimodipine, 60 mg every 4 hours (an intravenous preparation is available in some countries). Hypotension should be avoided.
- Maintain euvolemia. It is common for patients to present with volume depletion. Some experts advocate gentle intravascular volume expansion. Significant cardiac injury can occur as result of catecholamine levels; thus, careful attention to arrhythmias and cardiac function is necessary.
- Avoid hyponatremia, which is commonly encountered. Normal saline has been used as the primary intravenous fluid although some experts now advocate chloride-sparing infusions unless hyponatremia is prominent. Hyponatremia usually reflects cerebral salt wasting rather than SIADH and should **NOT** be treated with volume restriction. Both traumatic and nontraumatic SAH patients will have inappropriately high urine osmolality, so this marker cannot be used to indicate SIADH. If salt administration is indicated, hypertonic saline is the treatment of choice. Hyponatremia should be corrected slowly because central pontine myelinolysis can occur from rapid and aggressive sodium correction.
- Seizure prophylaxis should be considered for patients until the aneurysm is secured. Active treatment of seizures should be done according to guidelines and protocols.
- Treat pain and anxiety. It is important to avoid straining or Valsalva because either can potentially contribute to aneurysm rupture. A balance should be achieved between oversedation and undermanagement of pain and anxiety because one could mask symptoms of neurologic deterioration. Consider medications with a short half-life.
- Antiemetics may be helpful in preventing discomfort and strain associated with vomiting.
- Because this disease requires the combined efforts of intensivists, neurosurgeons, and neurointerventionalists, it is prudent to manage patients in centers with the capacity for aneurysm clipping and coiling and for vasospasm treatment.

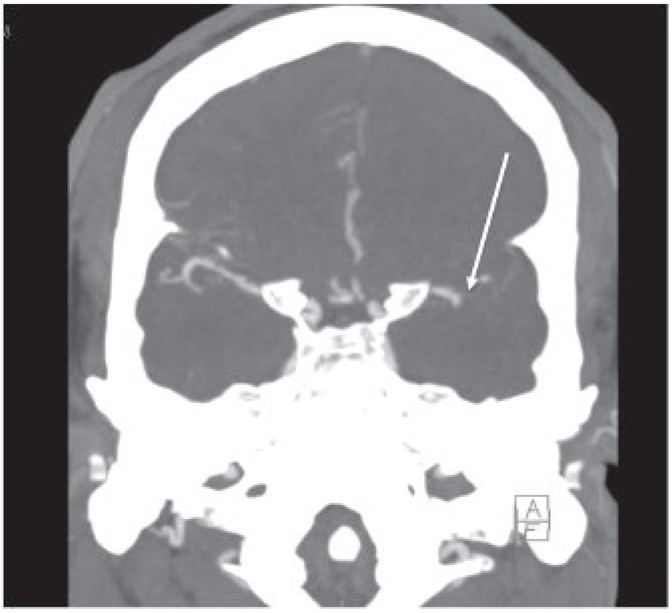
Abbreviations: CSF, cerebral spinal fluid; EVD, external ventricular drain; SIADH, syndrome of inappropriate antidiuretic hormone

D. Ischemic Stroke

Stroke is a leading cause of disability. In the United States alone, there are approximately 750,000 strokes each year. Of these patients, 15% to 30% are disabled, 20% require long-term institutional care, and 50% are unable to return to work. The estimated cost of stroke in the United States is $72 billion. Ischemic stroke usually occurs because of thromboembolic obstruction of arteries. Administration of intravenous recombinant tissue plasminogen activator (t Pa) during the first 3 to 4.5 hours following the known onset of ischemic stroke substantially improves outcome in one-third of patients. Recent studies have demonstrated a role for intra-arterial treatment with a clot retrieval system (called a stent-retriever device) in selected patients with larger artery occlusion if they present within the first 24 hours of symptoms (**Figure**

9-4). This aggressive intervention results in the impressive relative reduction of disability in 73% of patients.

Figure 9-4. CT Angiogram Demonstrating Occlusion of Left Middle Cerebral Artery (arrow)



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The use of a stroke severity rating scale, such as the National Institutes of Health Stroke Scale (NIHSS), is recommended.

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Onset of symptoms, or the last time the patient was known to be at baseline (often called Last Known Well [LKW]), is the time used to determine whether a patient is a candidate for thrombolytic therapy. The use of a stroke severity rating scale, such as the National Institutes of Health Stroke Scale (NIHSS) is recommended. Like the GCS, it forms a common language by which to risk-stratify patients for treatment. After an initial CT scan rules out the presence of hemorrhage, intravenous recombinant tPA should be administered in a dosage of 0.9 mg/kg (10% as a bolus over 1 minute and 90% in a 1-hour infusion) for patients in whom treatment can be started within 4.5 hours. Protocols should be in place, including absolute and relative contraindications, to ensure proper selection of candidates for thrombolytic therapy. Personnel who are not familiar with the use of recombinant tPA for the acute treatment of non-hemorrhagic stroke should seek immediate neurologic consultation before administering therapy. Intra-arterial clot retrieval is an important option for patients with large artery occlusion, regardless of whether recombinant tPA has been administered. Guidelines are available from the AHA/ASA.

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In an otherwise eligible patient for acute reperfusion patient whose BP is >185/110 mm Hg, anti-hypertensive medications such as labetalol, nicardipine, clevidipine, hydralazine and enalaprilat can be used to lower and maintain target BP. Please refer to AHA guidelines for BP management protocol.

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Supportive care includes management of hypertension. Although an elevated BP is often present early, a decrease in pressure usually occurs in the first hours after stroke without specific medical treatment. No evidence defines a level of BP that requires emergent intervention. The AHA and ASA have compiled consensus recommendations for patients who are candidates for thrombolytic therapy. For those patients who are not candidates for thrombolysis, emergency administration of antihypertensive agents is not indicated unless the diastolic BP is > 120 mm Hg, SBP is > 220 mm Hg, or there is evidence of end-organ injury (eg, pulmonary edema). If treatment is indicated, the BP should be lowered cautiously with a reasonable goal of lowering the pressure approximately 15% in the first 24 hours after stroke onset.

If a patient deteriorates clinically during or after IV tPA, the clinician should stop tPA infusion immediately, monitor vital signs, obtain head CT stat and if confirmed hemorrhage, administer cryoprecipitate. Significant edema formation, typically within the first 72 hours, or extensive hemorrhage within the ischemic zone may indicate the need for emergent hemicraniectomy. Younger patients with middle cerebral artery (MCA) or internal carotid artery (ICA) infarction should be considered for decompressive hemicraniectomy within 48 hours of the onset of symptoms. Medical management includes osmotic therapy, sedation, prevention of secondary brain injury (avoid hypotension and hypoxia), early nutrition, glucose control (range 140–180 mg/dL), temperature control, and venous thromboembolism (VTE) prophylaxis.

Determination of when the initial stroke symptoms appeared is critical.

VTE prophylaxis should be administered to immobilized patients. Low-molecular-weight heparins are favored in relation to unfractionated heparin, although both could be similarly effective. No data are available on the use of new oral anticoagulants. Aspirin administration within 24 to 48 hours of the onset of the stroke is recommended for most patients after hemorrhage is excluded. In patients with minor strokes, treatment for 21 days with dual antiplatelet therapy (aspirin and clopidogrel) started within 24 hours can be beneficial for early secondary stroke prevention.

E. Anoxic Injury

Relative anoxia may be a part of other injuries and may be the result of airway loss, systemic hypoxemia, hypoperfusion, and other causes. Anoxia may also be the primary brain insult, as occurs during cardiac arrest. Neuronal damage may occur as a direct result of the primary insult of hypoxemia or hypoperfusion.

The initial team should maintain the usual standards of optimal oxygen delivery. Despite extensive studies of many agents and therapy options, none has proven selectively beneficial, nor has the poor prognosis from anoxic brain injury improved over time. The International Liaison Committee on Resuscitation (ILCOR) task force recommends targeted temperature management for adults with out-of-hospital cardiac arrest with an initial shockable rhythm at a constant temperature between 32°C to 36°C (89.6°F to 96.8°F) for at least 24 hours. Guidelines are available from the AHA and the ILCOR.

F. Metabolic Abnormalities, Infectious Emergencies, and Seizures

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In the absence of papilledema or focal neurologic signs, a lumbar puncture may be performed without a prior CT scan for evaluation of meningitis.

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In adult patients with depressed consciousness after airway management and initial resuscitation, the administration of 50% dextrose (50 mL intravenously) and thiamine (100 mg intravenously) should be considered for the treatment of potential hypoglycemia and the prevention of Wernicke encephalopathy if an immediate determination of the blood glucose concentration is not available. Intravenous naloxone should be administered if narcotic intoxication is a possibility. Other metabolic abnormalities, such as electrolyte disorders (ie, acute hyponatremia, hypercalcemia), liver failure, or uremia may also cause coma. Because headache or altered state of consciousness accompanied by fever, nuchal rigidity, and leukocytosis suggests meningitis or encephalitis, the CSF should be submitted for physical, chemical, and bacteriologic (culture and Gram stain) studies. If clinical examination suggests a mass lesion or elevated ICP, a CT scan should be performed before lumbar puncture. If the scan reveals evidence of mass effect or generalized cerebral edema, a lumbar puncture may precipitate a herniation syndrome and should be postponed. When infection is part of the differential diagnosis, appropriate antibacterial and antiviral treatment should be initiated before performing the imaging study or lumbar puncture because early therapy for bacterial meningitis or encephalitis may be lifesaving. Blood cultures should be obtained before antibiotic therapy unless this would delay treatment. Antibiotics and resuscitation should not be delayed to obtain a lumbar puncture or brain CT. Treatment recommendations are outlined in **Chapter 11**.

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If possible, avoid the use of neuromuscular blocking agents in patients at risk for seizure because these agents obscure detection of seizure activity.

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G. Status Epilepticus

Status epilepticus (SE) is a life-threatening neurologic emergency that requires prompt treatment and diagnosis. It is defined as 5 minutes or more of continuous seizure activity or recurrent seizure activity without return to baseline. It may be classified as convulsive and non-convulsive. The treatment management plan should include work-up to determine possible etiologies and rapid protocol for termination of seizures.

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Possible etiologies of Status Epilepticus
Acute: CNS infection, metabolic, TBI, sepsis, stroke, drugs, hypoxia, cardiac arrest, hypertensive encephalopathy, autoimmune encephalitis

Chronic: Breakout seizures, CNS tumors, alcohol withdrawal

Intravenous benzodiazepines are administered at the onset of prolonged or repeated seizure activity. Status epilepticus requires emergent neurologic consultation, and lorazepam 0.1 mg/kg should be administered intravenously. Intramuscular midazolam, 0.15 mg/kg, is an alternative if intravenous access is not immediately available. The addition of phenytoin/fosphenytoin, valproate sodium, or levetiracetam has been shown to be useful. If seizures continue, secure the airway and initiate advanced treatment for refractory SE. Anticonvulsants used in refractory SE include propofol (3 mg/kg loading dose, then infusion of 1–5 mg/kg/h) or midazolam (0.2 mg/kg loading dose, then infusion of 1–20 μg/kg/min) with electroencephalography and other ICU monitoring.

Seizure activity after an acute brain injury increases cerebral oxygen requirements and typically elevates ICP. Appropriate therapy should be administered to terminate seizure activity as soon as possible. The intravenous administration of anticonvulsants, many of which have a potent sedative effect, may depress respiratory function and requires appropriate supportive therapy. In addition, hypotension may occur, requiring additional intravenous fluids and/or vasopressors to preserve MAP and CPP.

H. Spinal Cord Injury

Cervical spine injury can usually be determined in awake patients because they reflect neck pain and weakness. If awareness is impaired, cervical spinal cord injury should be suspected in patients with respiratory weakness, extremity weakness without facial weakness, hypotension with bradycardia, priaprism in male patients, and difficulty maintaining normothermia. Patients with lesions below the fourth cervical segment (C4) may breathe adequately on presentation but could progress to respiratory failure with abrupt decompensation and thus must never be left unmonitored.

Thoracolumbar spine injury spares the upper extremities but involves leg weakness; depending on the spinal level, the patients may have hypotension with tachycardia or unusual swings in BP.

Initial management includes spinal motion restriction (cervical collar, backboard) while obtaining emergent spine surgery consultation. However, patients should not be left on backboards after arrival in the emergency department because of the risk of pressure ulcer development. A MAP of $>$ 85 mm Hg for the first 7 days after injury is recommended by some clinicians to improve perfusion to the injured area of cord. The American Association of Neurological Surgeons/Congress of Neurological Surgeons do not recommend the use of methylprednisolone in spinal cord injury.

CT scans of the spine can be obtained without removing immobilizing devices.

I. Other Neurologic Causes of Acute Respiratory Failure (Acute Nontraumatic Weakness)

Patients with conditions causing global weakness, such as myasthenia gravis and Guillain-Barre syndrome, may have problems maintaining upper airway patency in addition to respiratory muscle weakness. In such patients, endotracheal intubation may be warranted for airway protection before being mandated by the falling tidal volume. Measurement of vital capacity and negative inspiratory pressure is important. Patients with increased work of breathing, hypoxemia, $<$ 20 mL/kg vital capacity, or maximum inspiratory pressure $<$-30 cm H_20 should be moved to the ICU and will likely need intubation soon. Intubation should be based on tachypnea and discomfort without waiting for an elevation of $PaCO_2$. Hypoxia as a result of atelectasis in patients with adequate airway protection may be treated with continuous positive airway pressure if airway protection is not a concern. A neurologist should be consulted when the diagnosis is suspected because treatment with intravenous immunoglobulin or plasma exchange may slow or halt disease progression and speed recovery. Autonomic dysfunction is common in the Guillain-Barre syndrome and may lead to large and rapid swings in BP and heart rate requiring intravenous therapy.

J. Death by Neurologic Criteria (Brain Death) and Organ Donation

Despite the best efforts of medical and surgical teams, massive injury, cerebral infarction, anoxia, or hemorrhage may result in a loss of all cerebral and brainstem functions. Evaluation of brain death and the guidelines for organ donation are variable, depending on the country, state, and facility. For more information about brain death and organ donation, see **Appendix 3** and **4**.

Key Points

Neurologic Support

- Brain injury occurs as a consequence of a primary insult and secondary injury. The prevention of secondary brain injury is a critical goal for the initial care team.
- The most significant mechanisms for secondary injury in brain-damaged patients are hypotension and hypoxia.
- Optimizing oxygen delivery while controlling oxygen consumption is a general treatment principle for all types of brain injury.
- Important principles and guidelines for initial treatment apply to all types of primary brain injury and help prevent harmful secondary sequelae.
- BP management is dependent on the initial brain injury. However, excessive lowering of BP in any acute brain injury may induce secondary ischemia.
- Avoid prophylactic or routine hyperventilation in patients with brain injuries. Mannitol should be administered for signs of downward herniation or if neurologic deterioration is not attributable to other factors. Hyperventilation may be initiated cautiously as a temporizing measure.

- Ensure euvolemia using normal saline as the primary maintenance fluid.
- Seizure activity after acute brain injury should be terminated with an intravenous dose of a benzodiazepine, followed by an intravenous loading dose of an antiepileptic drug.

Suggested Readings

1. Albers GW, Marks MP, Kemp S, et al. Thrombectomy for stroke at 6 to 16 hours with selection for perfusion imaging. DEFUSE 3 Investigators. *N Engl J Med*. 2018;378(8): 708-718.
2. Bleck TP. Bacterial meningitis and other nonviral infections of the nervous system. *Crit Care Clin*. 2013;29(4):975-987.
3. Boland TA, Lee VH, Bleck TP. Stress-induced cardiomyopathy. *Crit Care Med*. 2015;43(3):686-693.
4. Brain Trauma Foundation, American Association of Neurological Surgeons, Congress of Neurological Surgeons, AANS/CNS Joint Section on Neurotrauma and Critical Care. Guidelines for the management of severe traumatic brain injury. 4th ed. 2016;1-:- Retrieved from www.braintrauma.org.
5. Brophy GM, Bell R, Claassen J, et al. Guidelines for the evaluation and management of status epilepticus. *Neurocrit Care*. 2012;17(1):3-23.
6. Busl KM, Bleck TP. Neurogenic pulmonary edema. *Crit Care Med*. 2015;43(8):1710-1715.
7. Callaway CW, Donnino MW, Fink EL, et al. Part 8: Post–cardiac arrest care: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation*. 2015;132(18 Suppl 2):S465–S482.

8. Chesnut RM, Bleck TP, Citerio G, et al. A consensus-based interpretation of the Benchmark Evidence from South American Trials: Treatment of Intracranial Pressure Trial. *J Neurotrauma*. 2015;32(22):1722-1724.

9. Connolly ES, Rabenstein AA, Carhuapoma JR, et al. Guidelines for the management of aneurysmal subarachnoid hemorrhage: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2012;43(6):1711-1737.

10. DeNett T, Feltner C. Hypertonic saline versus mannitol for the treatment of increased intracranial pressure in traumatic brain injury. *J Am Assoc Nurse Pract*. 2019;4:2327-6924.

11. Diringer MN, Bleck TP, Claude Hemphill J 3rd, et al. Critical care management of patients following aneurysmal subarachnoid hemorrhage: recommendations from the Neurocritical Care Society's Multidisciplinary Consensus Conference. *Neurocrit Care*. 2011;15(2):211-240.

12. Donnino MW, Andersen LW, Berg KM, et al. ILCOR Advisory Statement. Temperature Management After Cardiac Arrest. *Circulation*. 2015;132(25):2448-2456.

13. Hawryluk GWJ, Aguilera S, Buki A, et al. A management algorithm for patients with intracranial pressure monitoring: the Seattle International Severe Traumatic Brain Injury Consensus Conference (SIBICC). *Intensive Care Med*. 2019;45(12):1783-1794.

14. Hemphill JC, Greenberg SM, Anderson CS, et al. Guidelines for the management of spontaneous intracerebral hemorrhage: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2015;46(7):2032-2060.

15. Hutchinson PJ, Kolias AG, Timofeev IS, et al. Trial of decompressive craniectomy for traumatic intracranial hypertension. *N Engl J Med*. 2016;375(12):1119-1130.

16. Kapur J, Elm J, Chamberlain JM, et al. Randomized trial of three anticonvulsant medications for status epilepticus. *N Engl J Med*. 2019;381(22):2103-2113. DOI:10.1056/NEJMoa1905795.

17. Kotloff RM, Blosser S, Fulda GJ, et al. Management of the potential organ donor in the ICU: Society of Critical Care Medicine/American College of Chest Physicians/Association of Organ Procurement Organizations Consensus Statement. *Crit Care Med*. 2015;43(6):1291-1325.

18. Liu Y, Qiu H, Su J, et al. Drug treatment of cerebral vasospasm after subarachnoid hemorrhage following aneurysms. *Chin Neurosurg Jl*. 2016;2(4).

19. Munoz J, Keough EA, Barrios JC, et al. Primary decompressive craniectomy in neurocritical patients. A meta-analysis of randomized controlled trials, cohort and case-control studies. *J Emerg Crit Care Med*. 2018;2(9).

20. Nogueria RG, Ashutosh PJ, Haussem DC, et al. Thormbectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. DAWN Trial Investigators. *N Engl J Med*. 2018:378(1):11-21.

21. Powers WJ, Rabinstein AA, Ackerson T, et al. 2018 American Heart Association/American Stroke Association guidelines for the early management of patients with acute ischemic stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2018;49(3):e46-e110.

22. Rossetti AO, Bleck TP. What's new in status epilepticus? *Intensive Care Med*. 2014;40(9):1359-1362.

23. Shank CD, Walters BC, Hadley MN. Current topics in the management of acute traumatic spinal cord injury. *Neurocrit Care*. 2019;30:261-271.

24. Shemie SD, Hornby L, Baker A, et al. International guideline development for the determination of death. *Intensive Care Med*. 2014;40(6):788-797.

25. Silbergleit R, Durkalski V, Lowenstein D, et al. Intramuscular versus intravenous therapy for prehospital status epilepticus. *N Engl J Med*. 2012;366:591-600.

26. Torbey MT, Bosel J, Rhoney DH, et al. Evidence-based guidelines for the management of large hemispheric infarction: a statement for health care professionals from the Neurocritical Care Society and the German Society for Neurointensive Care and Emergency Medicine. *Neurocrit Care*. 2015;22(1):146-164.

27. Vahedi K, Hofmeijer J, Juettler E, et al. Early decompressive surgery in malignant infarction of the middle cerebral artery: a pooled analysis of three randomised controlled trials. *Lancet Neurol*. 2007;6(3):215-222.

28. Walters BC, Hadley MN, Hurlbert RJ, et al. Guidelines for the management of acute cervical spine and spinal cord injuries: 2013 update. *Neurosurgery*. 2013;60(Suppl 1): 82-91.

29. Wilson MH. Monro-Kellie 2/0: The dynamic vascular and venous pathophysiological components of intracranial pressure. *J Cereb Blood Flow Metab*. 2016;36(8):1338-1350.

Suggested Websites

1. Society of Critical Care Medicine/Guidelines. www.SCCM.org.
2. Brain Trauma Foundation. http://www.braintrauma.org.
3. Brain Attack Coalition. http://www.brainattackcoalition.org.

4. Neurocritical Care Society. http://www.neurocriticalcare.org.

Chapter 10

NEUROSURGICAL ICU

✓ Objectives

- Review the physiology of cerebrospinal fluid (CSF) composition, production, circulation, and resorption.
- Discuss the physiology of intracranial pressure (ICP) and cerebral perfusion pressure (CPP).
- Review the presentation, diagnosis, and management of acute intracranial hypertension and hydrocephalus.
- Describe the insertion, maintenance, and troubleshooting of external ventricular drains (EVD).
- Define and outline the management of syndrome of inappropriate antidiuretic hormone secretion (SIADH), cerebral salt-wasting syndrome (CSWS), and diabetes insipidus (DI) as they relate to sodium abnormalities in patients with neurologic issues.
- Discuss the recognition, management, and prevention in a patient with cerebral vasospasm.
- Identify the physiologic sequelae in spinal cord injury and neurogenic shock.
- Review steps to initiate management for the patient with neurogenic shock.

Case Study

A 42-year-old man with no significant medical history experiences sudden onset of the worst headache of his life during strenuous exercise. The patient is taken to the emergency department (ED) of the local hospital by his family. The ED physician obtains a computed tomography scan (CT) of the head that shows subarachnoid blood over the cerebral convexities and in the left Sylvian fissure. A small amount of blood is seen in the dependent lateral ventricles with prominence of the temporal horns. Early surgical and neurointerventional consultations are obtained. The Glasgow Coma Scale (GCS) score on admission is 11. The consulting neurosurgeon notes that the patient is lethargic. The patient is admitted to the ICU. Measures are taken to maintain adequate blood pressure control, pharmacologic vasospasm prophylaxis, and a four-vessel cerebral angiogram is ordered. The patient has embolization of a right anterior communicating artery aneurysm a few hours after admission. Upon arrival back to the ICU, he is minimally responsive and vomits. His GCS score is now 6.

– Why did the patient's neurologic examination worsen?

– What immediate interventions are required?

I. INTRODUCTION

Neurosurgical patients can present unique challenges to the treating clinician. Many symptoms are subtle combined with patient's inability to express them can lead to delay in diagnosis and unwanted complications. Many neurocritical care emergencies can present special challenges and one must have a high index of suspicion for the diagnosis and be able to provide timely interventions to prevent catastrophic complications and consequences. In managing certain neurocritical patients and conditions we need to follow specific guidelines that sometimes don't apply to the general surgical or medical patient.

II. HYDROCEPHALUS

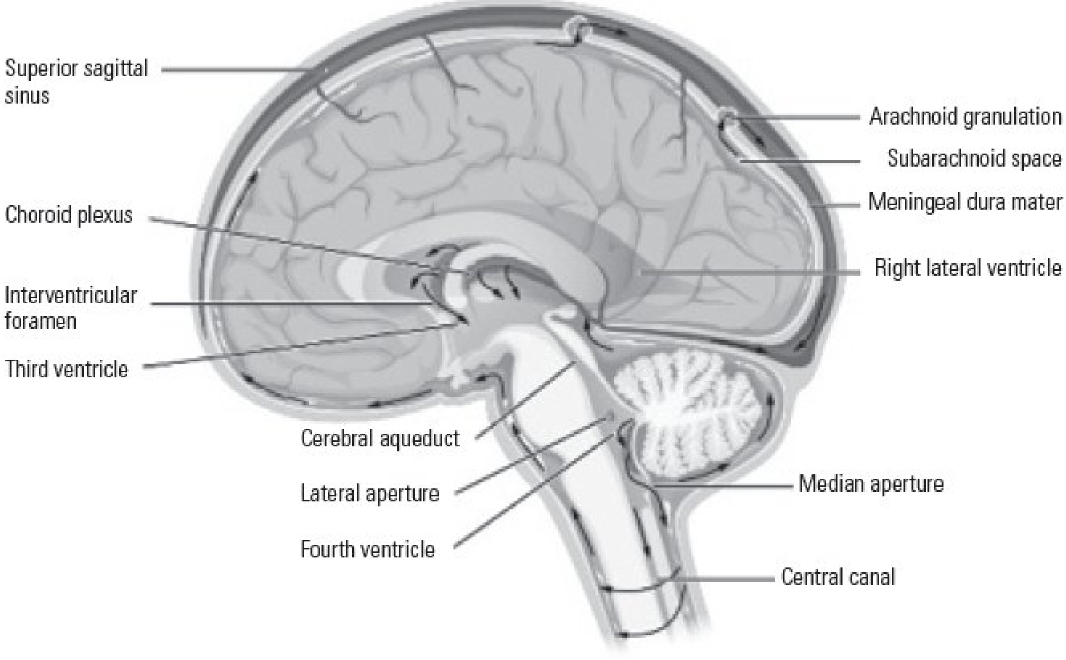
A. Introduction and Physiology

When CSF absorption decreases, unless another intracranial volume (soft tissue or blood) decreases to compensate, the rapid increase in CSF volume will cause a rapid increase in ICP.

In healthy individuals, the production and reabsorption of the cerebrospinal fluid (CSF) is maintained constant and in balance. Hydrocephalus occurs when CSF accumulates in the brain, causing increased pressure within the skull. CSF is a clear acellular saline solution with density and viscosity like that of water, produced continuously in the subarachnoid space at a rate of approximately 25–30 mL/hr (approximately 600–700 mL/day) as blood flows through the choroid plexus located in the lateral ventricles and in the subarachnoid space next to the cerebellopontine angles (**Figure 10-1**). The total volume of CSF in the entire subarachnoid space is approximately 125–150 mL, while the ventricles of the normal brain contain approximately 25–30 mL. The volume of CSF in normal ventricles is only 1.5 to 2.0 times that of the volume of CSF produced in an hour.

Normally CSF production and reabsorption are balanced so that the total volume is constant. CSF moves from the subarachnoid space into the venous circulation and ultimately to the kidneys where it is excreted in the urine.

Figure 10-1. Cerebrospinal Fluid (CSF) Production and Flow


Superior sagittal sinus
Arachnoid granulation
Subarachnoid space
Meningeal dura mater
Choroid plexus
Right lateral ventricle
Interventricular foramen
Third ventricle
Cerebral aqueduct
Lateral aperture
Fourth ventricle
Median aperture
Central canal

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The Monro-Kellie hypothesis relates pressure in the non-expansible intracranial compartment to the sum of the volumes of the tissues contained therein (**Figure 10-2**).

- Soft, semi-solid tissue, normal and pathologic (brain parenchyma, hematoma, tumor)
- CSF (intraventricular and subarachnoid)
- Intradural blood vessels (arteries and veins) within and on the surface of the brain

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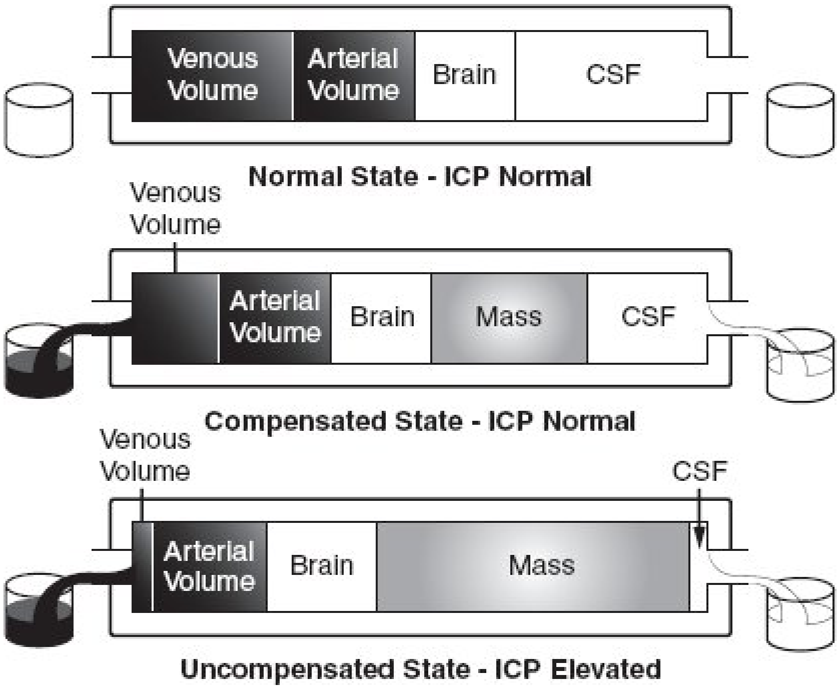
According to the Monro-Kellie hypothesis, the only way to decrease ICP is by decreasing the volume of one or more intracranial compartments:

1. *Soft tissue (brain or mass lesion),*
2. *Blood (intravascular), and/or*
3. *CSF.*

Because the cranium is non-compressible and has a fixed volume, the compartments inside the cranium (brain tissue, blood, CSF) are in equilibrium. Any increase in the volume of one compartment will have to be balanced by a decrease in the volume of another; otherwise the intracranial pressure (ICP) will increase and the CSF and blood will be displaced downward through the path of least resistance.

Cerebral perfusion is a function of the forward-driving force of blood imparted by the contractions of the heart that must overcome the resistance of pressure inside the cranium. The calculation for cerebral perfusion pressure (CPP) is mean arterial pressure (MAP) minus intracranial pressure (ICP):

Figure 10-2. Monro-Kellie Hypothesis


Venous Volume
Arterial Volume
Brain
CSF
Normal State - ICP Normal
Venous Volume
Arterial Volume
Brain
Mass
CSF
Compensated State - ICP Normal
Venous Volume
CSF
Arterial Volume
Brain
Mass
Uncompensated State - ICP Elevated

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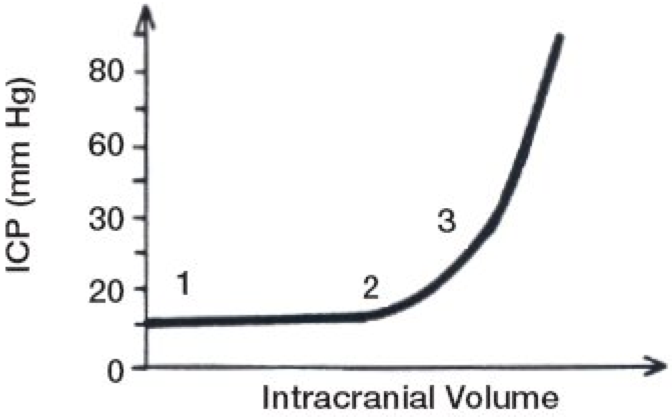
CPP = MAP − ICP

Neurons are physiologically stressed below a critical threshold of 60 mm Hg, while a CPP of 70–80 mm Hg or greater is adequate for oxygen delivery to sustain neuronal metabolism and electrical activity.

Symptomatic acute hydrocephalus is considered an emergency because CSF continues to accumulate even when absorption slows or stops (this is called communicating hydrocephalus) or when there is a blockage along the CSF circulation pathway (this is called non-communicating hydrocephalus). Adding 25–30 mL/hr of CSF to ventricles with a normal volume of 35–50 mL and limited compliance (ability to expand) will cause intraventricular pressure to rise rapidly (**Figure 10-3**). The clinician should assume that decompensation is imminent and that there will be a rapid increase in the slope of the pressure-volume curve with each additional milliliter of CSF added to the ventricular volume. When this occurs, CSF must be immediately drained to prevent an acute, dramatic increase in ICP with decrease in CPP to the ischemic or even anoxic range. Failure to do so will result in irreversible neurologic deficit, coma, or death.

Figure 10-3. Pressure-Volume Curve



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B. Presentation, Signs, and Symptoms

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The rapidity of onset of symptoms and signs of increased ICP determines the urgency with which ICP must be controlled and lowered.

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Because presenting signs and symptoms of acute hydrocephalus are similar to those of other intracranial pathology that increase ICP, a careful history and neurologic examination of the patient are essential to diagnose hydrocephalus. Headache (with or without vomiting) is the most common symptom in a patient who is awake. Altered consciousness, irritability, sleepiness, lethargy, and obtundation are the most common signs of ICP-related global neurologic compromise.

The rapidity of onset of signs and symptoms is the most significant factor in determining how urgently to treat acute hydrocephalus. A history of recent and sudden change in ICP dynamics and failure to maintain ICP via the Monro-Kellie compensatory mechanism suggests that, without immediate intervention, CSF volume and ICP will continue to rise. This will put the patient at risk for rapid deterioration and progression to coma and death. A history of hemorrhage, infection, tumor, or ventriculoperitoneal shunt (or other CSF shunt) with symptoms and/or signs consistent with acutely elevated ICP is also an indication for imaging to rule out hydrocephalus.

Seizures are sometimes a result of the pathophysiologic process (such as tumor or infection) that causes acute hydrocephalus, but isolated new onset or increased frequency of seizures is seldom caused by hydrocephalus. Regardless of how rapidly or slowly the pathophysiology progresses, clinical progression to severe headache, lethargy, or cranial nerve palsy are indicators for immediate intervention to lower ICP.

Other symptoms and signs include vomiting, snoring and gurgling, and fever. Vomiting can be an indication that ICP is high and rising rapidly. Snoring and gurgling breathing are alarming signs suggestive of worsening level of consciousness. Fever can occur in association with acute shunt obstruction, especially with infection.

Patients with elevated ICP, and especially nearing critical stages (nearing herniation), might develop what is called the Cushing reflex, or Cushing's triad. Cushing's triad consists of the following:

- Abnormal breathing pattern
- Hypertension
- Bradycardia

Many patients with acute hydrocephalus do not present with Cushing's triad. However, the diagnosis should be considered, and emergency neurosurgical consultation expedited when a patient presents with one or more of these vital sign changes.

The thresholds for hypertension and bradycardia are different for small children. In a baby, a heart rate of 80 beats/min may be bradycardic. Symptoms and signs of acute hydrocephalus may be harder to pick up in children who are uncooperative, irritable, and agitated. A pediatrician should follow any child admitted with suspected acute hydrocephalus.

As noted previously, global neurologic findings such as alteration in the level of consciousness, confusion, lethargy, and obtundation are most common with acute hydrocephalus. On neurologic examination, a sixth nerve palsy is indicative of an increase in ventricular size sufficient to stretch the cranial nerve. Papilledema can be found if ICP has been elevated for several hours or more.

C. Shunts

Shunts are the most common long-term treatment for hydrocephalus. Acute hydrocephalus caused by shunt obstruction is near the top of the differential of any rapid change in mental status in a patient with a ventriculoperitoneal (VP), ventriculopleural, or other CSF shunt.

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Because CSF is so rapidly produced, a sudden complete obstruction of flow from the ventricles into the peritoneal cavity is a neurosurgical emergency. Without either an emergency shunt revision or placement of an additional external ventricular drain, ICP will rapidly rise and the patient will become progressively lethargic, obtunded, and ultimately comatose.

Shunts are placed in premature infants with intraventricular hemorrhage, newborns with myelomeningocele and other neural tube anomalies, post-meningitis, and for congenital stenosis of the Sylvian aqueduct. Shunts are so effective at keeping ICP low and are inconspicuous under the scalp and skin so that many adults who had one placed as a child forget they have one. Examination for a shunt should be part of the physical examination of any patient, child or adult with acute mental status changes.

Patients can usually recognize a shunt malfunction with symptoms such as a headache or double vision. The parent of a developmentally delayed or noncommunicative child who underwent placement of a shunt early in childhood and has had VP shunt revisions will often recognize acute shunt failure because the child's symptoms and signs mirror those present before the shunt revisions.

Shunt infections are more common in children but can also occur in adults. Any patient with a VP shunt who presents with symptoms of acute hydrocephalus should have CSF withdrawn and sent for analysis (WBC, glucose, protein) and culture to rule out infection.

Patients with normal pressure hydrocephalus have the classic symptoms of cognitive impairment, imbalanced gait, and urinary incontinence. They have a VP shunt placed to control their symptoms. Acute onset of altered mental status in a patient shunted for normal pressure hydrocephalus is almost never due to shunt failure because the shunt was placed to lower already low ICP. The altered mental status is usually due to infection or development of a chronic subdural collection.

The design of VP shunts is simple, making it straightforward to identify the reason for malfunction based on history and examination.

1. Partial Obstruction

Increased ICP elevation due to partial shunt obstructions may progress more slowly than when due to completely obstructed flow but can eventually result in dangerously elevated ICP.

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Partial obstructions slow, but do not completely stop, CSF flow. The increase in ventricular volume and CSF pressure and associated symptoms and signs is more indolent but ultimately reaches the point of decompensation on the pressure-volume curve. Sometimes a neurosurgeon can tell from the resistance to withdrawing CSF or from the rate of flow into the abdomen through the clear tubing attached to the butterfly shunt tap needle that obstruction is only partial, but even a partial obstruction requires prompt revision.

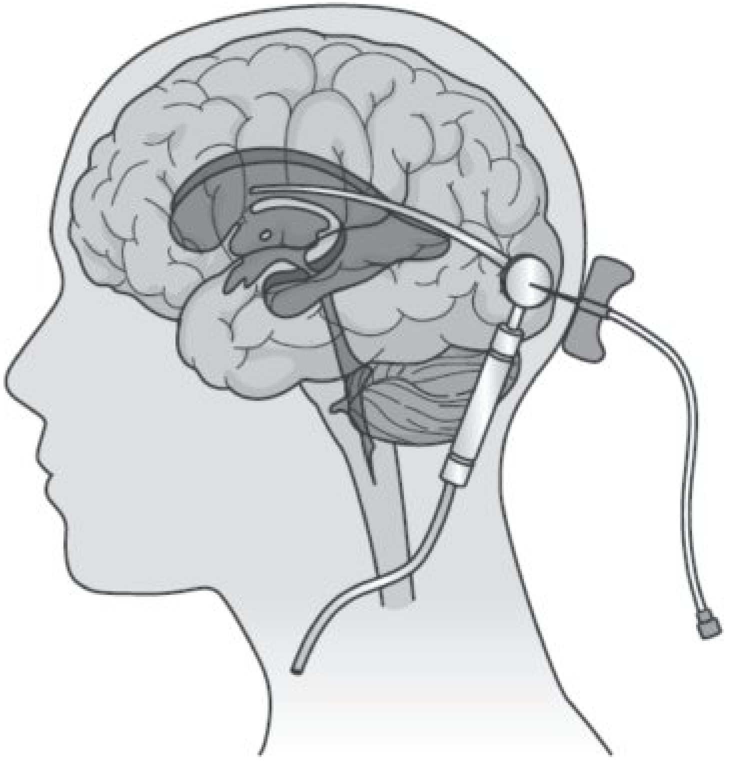
2. Proximal Obstruction

CSF enters the intraventricular portion of the shunt catheter through small (approximately 1-mm diameter) holes. Because the diameter of the inflow holes and ventricular catheter is small, clumps of particles small enough to enter the holes can block flow if their diameter is close to that of the ventricular catheter inner lumen or inflow holes. Even a partial VP shunt obstruction can result in an increase in CSF accumulation that overwhelms reabsorption, resulting in a rapid increase in intraventricular volume and ICP. A proximal obstruction should be suspected whenever there is a history of increased cellular or other biologic debris in the CSF. Inability to withdraw CSF with suction on a needle placed into the reservoir in sequence with the ventricular catheter suggests CSF inflow obstruction within the ventricles (**Figure 10-4**).

3. Disconnection

Any of the connections—ventricular catheter to reservoir, reservoir to valve, valve to peritoneal tubing—can become disconnected. A history of head, neck, or generalized shaking or jerking preceding formation of a tumescent swelling under the skin along the course of shunt tubing requires a radiograph of the head, chest, and or abdomen to rule out a disconnection. It should be assumed that there is minimal or no flow of CSF beyond the disconnection. If a disconnection is discovered incidentally in a patient without symptoms or signs of hydrocephalus, it may be that the patient no longer needs continuous drainage of CSF for ICP control.

Figure 10-4. Tapping and Draining the Reservoir of a Malfunctioning VP Shunt



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4. Distal Obstruction

A history of recent or multiple abdominal surgeries with headache, mental status changes, and ventricular volume increased from post-shunt baseline is suggestive of blockage of outflow from the intraperitoneal portion of the drainage tubing. Intraperitoneal bleeding or infection can also cause distal obstruction. Distal obstruction suggested by surgery is confirmed on tapping the shunt at the reservoir if the column of CSF sucked into the clear portion of the butterfly needle placed into the reservoir does not flow quickly and completely out of the tubing through the drainage tubing and into the abdomen. Distal obstruction of ventriculopleural shunts should similarly be suspected if there is new pathology in the pleural space and no CSF column flow on tapping of the reservoir.

5. Abdominal Surgery

Contamination of the peritoneal tubing by spilled intestinal contents is a concern, especially in patients who have had previous abdominal surgery. Frequently a general surgeon will ask a neurosurgeon to scrub in and examine shunt tubing intraoperatively during abdominal surgery, especially if there is a possibility of intestinal violation with leakage into the peritoneal space. If there is suspicion of contamination based on inspection or extent of surgical manipulation in proximity, the neurosurgeon may elect presumptive externalization with several days of external drainage and IV antibiotics with subsequent internalization (perhaps draining into a pristine pleural cavity) once CSF is confirmed to be sterile. (Possible contamination of ventriculopleural shunts should similarly be suspected when the pleural space is entered for surgical intervention.)

D. Ventriculostomy

An alternative to shunts that is increasingly popular over the past few years is the ventriculostomy (making a hole in the floor of the ventricle) that treats hydrocephalus by creating an alternative CSF circulation pathway that bypasses a focal obstruction. If the scar tissue proliferates over time and the ventriculostomy closes, CSF can accumulate above the floor of the third ventricle with recurrent hydrocephalus. If patency is compromised over a short period of time, hydrocephalus symptoms and signs can come on relatively acutely.

1. Tumor

Tumor masses can focally block flow along the CSF circulation pathway. Ventricles may dilate slowly over time if the mass obstructing flow is slow growing. Sometimes ventricular dilatation due to CSF circulation blockage by a slowly expanding tumor is asymptomatic. Asymptomatic ventriculomegaly does not always require surgical treatment but should be followed over time with serial imaging and neurologic examination surveillance.

2. Hemorrhage

> *Neurologic deterioration early after subarachnoid hemorrhage is frequently related to development of hydrocephalus.*

Acute hydrocephalus following subarachnoid hemorrhage (SAH) is due to accumulation of red cells and other particulate matter in the Pacchionian (arachnoid) granulations of the sagittal sinus. Hydrocephalus can develop quickly over a few hours after SAH but sometimes is seen shortly afterwards on presentation. Neurologic deterioration early after subarachnoid hemorrhage is more frequently related to development of hydrocephalus and not to rebleeding of an aneurysm.

Expansion of bleeding into the lateral ventricles from parenchymal basal ganglia bleeding (so-called hypertensive hemorrhage) introduces red blood cell debris into the subarachnoid CSF space which can also block reabsorption.

3. Infection

Meningitis is associated with an increase in the concentration of reactive proteins as well as debris from the breakdown of inflammatory and immune cells. A history of meningitis, especially if a shunt was placed for hydrocephalus, should prompt imaging to evaluate for ventriculomegaly.

Shunt infections are more common in children but can also occur in adults. CSF should be withdrawn and sent for analysis (WBC, glucose, protein) and culture to rule out infection in any patient with a VP shunt who presents with symptoms of acute hydrocephalus.

4. Postoperative

Brain surgery with bleeding into the subarachnoid space is sufficient to cause blockage of reabsorption along the sagittal sinus. A patient with a SAH who did not have hydrocephalus preoperatively and whose aneurysm ruptures intraoperatively during clipping should be monitored carefully for postoperative hydrocephalus.

E. Monitoring of Hydrocephalus

A CT scan of the head is adequate for assessment of ventricular size. Decreased tissue density can be seen around the ventricles when CSF is pushed across the ependymal wall into the surrounding brain parenchyma when ICP is elevated. A head CT is also adequate for demonstration of ventricular size and the presence of periventricular edema suggestive of increased ICP. Rapid CSF production and increasing ICP can cause a precipitous decline in mental status.

Large ventricles do not always correlate with symptomatic hydrocephalus. Ventricular enlargement is normal as the brain ages. The clinical presentation —history and physical examination—determine whether a patient's ventriculomegaly seen on head CT is acute or progressive hydrocephalus with elevated ICP that requires treatment, or is asymptomatic, long-standing, low-pressure ventriculomegaly.

MRI is not indicated for the workup of acute, life-threatening hydrocephalus. If the onset of symptoms is slowly progressive over several hours and a neurosurgeon is available to remove a lesion or bypass an obstruction of the CSF circulation, such as Sylvian aqueductal stenosis, AND if the patient is stable for transport AND can tolerate being still for 30 minutes in a narrow tube, an MRI may provide surgical strategy information that justifies the risks of taking the time to obtain the images.

Until the acutely elevated ICP is lowered with drainage of CSF, the patient is at risk for a rapid, geometric rise in ICP. The time frame for resolution of compromised consciousness and return of neurologic examination to baseline after an acutely elevated CSF pressure and volume is similar to that of deterioration at the inflection point of the pressure-volume curve in which smaller and smaller increments in CSF volume led to larger and larger increases in ICP and rapid progression toward coma.

F. Management of Hydrocephalus

1. Diuretics

Because the elevation in pressure is the result of additional fluid in the ventricles and not in the brain parenchyma (cerebral edema), osmotic diuresis to reduce interstitial fluid (and reduction of the Monro-Kellie soft-tissue compartment) will not significantly reduce or slow an increase in ICP due to acute hydrocephalus. Medications like acetazolamide that reduce the volume of CSF produced at the choroid plexus take hours to work and do not decrease production enough to restore the compromised CPP. A surgical pathway for drainage of CSF must be created before pressure reaches the dicrotic notch of the pressure-volume curve.

2. Analgesia and Sedation

Headache is the most common symptom of acute hydrocephalus. Untreated headache contributes to agitation and makes the patient less cooperative with imaging and monitoring. Heightened vigilance for acute loss of airway protective reflexes is crucial when sedation and systemic pain relief is being used on a patient with altered mental status caused by increased ICP. In most instances, it is recommended to protect the airway by intubating the patient who already has a marginal mental status that is going to get worse. Definitive treatment of headache caused by acute hydrocephalus is reduction of CSF volume.

3. Airway

> *If a patient is no longer able to protect their airway, becomes lethargic, or has evidence of hypercarbia while waiting for neurosurgical relief of intracranial hypertension, emergent intubation for airway protection and ventilatory assistance is indicated.*

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4. Cerebrospinal Fluid Volume Reduction

Drainage of CSF may have been initiated in the ED or the ICU team needs to be prepared to quickly set up for rapid insertion of a surgical CSF drainage system.

An emergent neurosurgical consult request should be placed for any patient with rapidly progressing decrease in consciousness with a head CT showing ventriculomegaly. All interventions for acute hydrocephalus should be performed by a neurosurgeon or other appropriately trained physician able to identify and manage any complications.

a. Lumbar Cerebrospinal Fluid Drainage

Lumbar drainage of CSF by tap is a reasonable temporizing measure for acute reduction in CSF volume and ICP. The volume of CSF that is removed by a lumbar puncture (10–20 mL) is rapidly replaced (25 mL/hr through the choroid plexus) such that keeping ICP low may require a lumbar drain that continuously drains CSF (usually around 10–20 mL/hr). ICP can be measured at the time of lumbar puncture but cannot be followed over time.

Lumbar drainage of CSF for control of ICP should only be done if intracranial imaging confirms no brain swelling or focal lesion near the foramen magnum where occlusion of flow could result in a pressure gradient between intracranial and intrathecal CSF that could lead to downward herniation and brainstem compression. If a neurosurgeon and the required equipment are available, the safest alternative to reducing CSF volume through a lumbar puncture is placement of an external ventricular drain (EVD).

b. Ventriculoperitoneal Shunt Tap

Neurosurgeons are trained to place a needle into the reservoir of the shunt (**Figure 10-5**) to withdraw CSF into a syringe. Withdrawal of a large volume (20 mL or greater) of CSF can result in almost immediate resolution of signs and symptoms in a patient with acute shunt failure. If access to an operating room (OR) is limited and a shunt revision is planned semi-electively, serial high-volume shunt taps can be done while waiting.

If CSF is drawn into clear tubing held straight up, the fluid column should decrease rapidly if there is free flow along the catheter into the peritoneal (or pleural) cavity. If the fluid column remains high there is most likely obstruction distally in the peritoneal tubing or outflow openings.

c. Non-Communication Lesion Removal

Based on symptoms and signs, if the patient's ICP clinically is low enough and not increasing so rapidly that there is concern that the patient will stop breathing or lapse into coma, emergency surgery can be temporarily deferred and the patient admitted to the ICU with frequent "neurologic checks" and expeditious identification and workup of a resectable lesion that is causing non-communicating hydrocephalus while setting up for an urgent craniotomy.

If there is any doubt that resecting a lesion that seems to be obstructing CSF flow will result in immediate resolution of hydrocephalus, it is best to place an EVD in the ICU or OR before the craniotomy, removing it only postoperatively after imaging confirms that the obstruction is relieved, flow is restored, transependymal edema is resolved, ICP is normal, and CSF drainage is not required to control ICP.

Occasionally postoperative imaging shows persistent ventriculomegaly even though the obstructing lesion has been completely removed. If the ventricles remain enlarged and the patient becomes symptomatic when the EVD is clamped, there is still hydrocephalus present and the patient will need conversion of the preoperative EVD to a permanent indwelling shunt.

G. External Ventricular Drain (EVD)

Although EVD insertion, maintenance, and troubleshooting are the purview of the consulting neurosurgeon, the critical care providers frequently manage patients with an EVD. An understanding of the principles of EVD design, insertion, maintenance, and troubleshooting is important.

1. Insertion

EVD placement is a surgical procedure that requires informed consent whenever possible. EVDs are placed under maximum sterile conditions. During placement in the ICU an assistant should be present at all times to hand the surgeon any instruments or other equipment that is not already on the sterile field.

Lethargic, uncooperative patients may need to be sedated to minimize movement during the procedure. Local anesthetic is used for potentially painful scalp incision, tunneling, and suture placement. Vital signs, oxygen saturation, and respiratory rate should be monitored during the insertion procedure. Even when the patient appears to be adequately sedated and is not moving as the procedure begins, the assistant should hold the patient’s head and chin under the drapes during incision, drilling, dual puncture, and catheter passage.

Essential elements of the procedure include:

- Side of insertion
- Number of attempted passes to successfully enter the ventricle
- Color and clarity of CSF obtained
- Identification of whether or not the fluid came out under pressure
- ICP when the fluid column pressure is measured

Post-procedure imaging for confirmation of catheter placement is not necessary as long as there is return of clear CSF after three or fewer passes. If there is no CSF on the third pass or if the CSF is bloody, a CT scan for catheter position and possible hematoma is indicated.

VP shunt obstruction due to infection requires conversion of the indwelling shunt to an external ventricular CSF draining system. The infected VP shunt should be removed and replaced with a sterile EVD, preferably placed on the opposite side of the head contralateral to the ventricle from which the infected catheter was removed.

If the acute obstruction is due to a process in the abdomen (or pleural space if the shunt is ventriculopleural), the distal portion of the draining catheter can be pulled upwards and out through an incision made just next to the catheter where it lies over the clavicle. The end of the catheter can then be connected to tubing draining into a bag so that CSF drainage continues until definitive revision of the shunt system can be done in the OR.

2. Shunt Externalization

> **!**
>
> *A neurosurgeon should be consulted for EVD:*
> *1. Indications for placement,*
> *2. Insertion,*
> *3. Oversight of maintenance,*

4. CSF withdrawal,
5. Removal.

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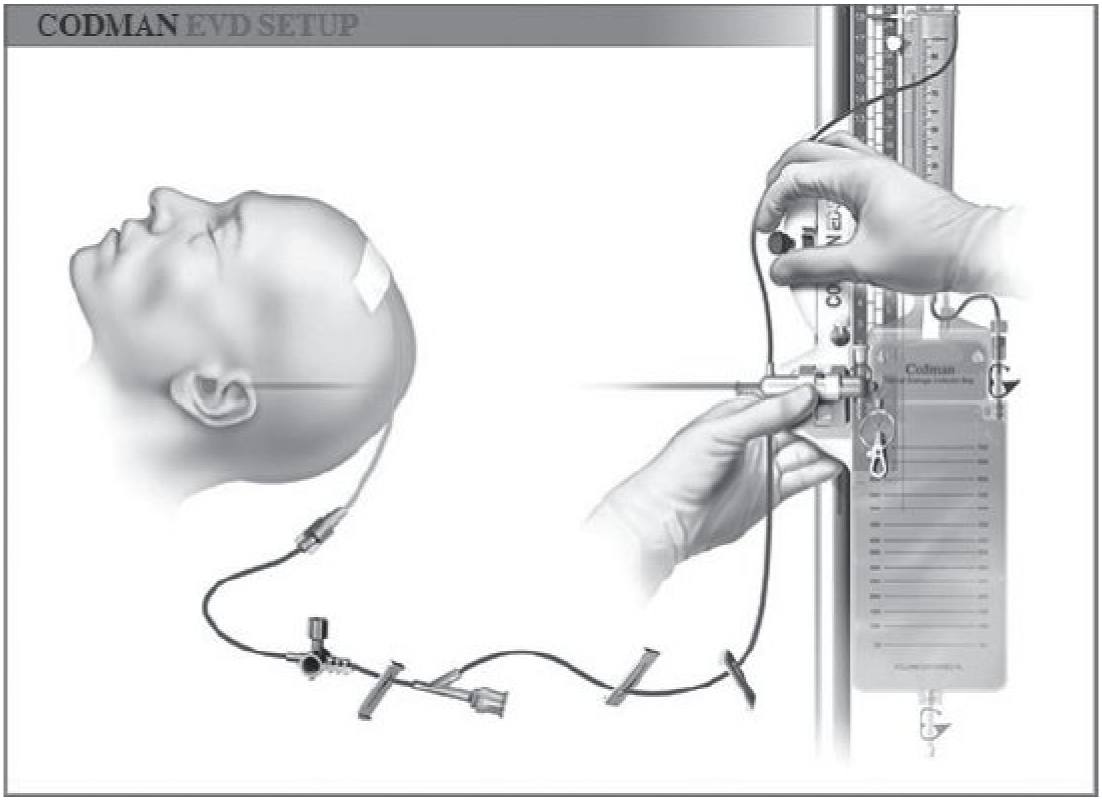
Externalization of a VP shunt creates an EVD. The subcutaneous peritoneal (or pleural) tubing can be pulled up and out through an incision made next to the tubing as it passes over the clavicle. The distal end of the externalized tubing can then be connected to tubing and a drainage bag. ICP pressure readings from partially externalized shunts are as reliable as with EVDs and comparable volumes of CSF can be drained. Bedside externalization is a good option for reducing acutely elevated ICP when VP shunt obstruction is distal (intra-abdominal or intrapleural) and no OR option is available.

3. Maintenance

CSF output and ICP should be recorded hourly. ICP measurements should be done with the head of the bed at 30 degrees and the pressure monitor zeroed at the level of the foramen of Monro (**Figure 10-5**).

Figure 10-5. External Ventricular Drain (EVD)



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The surgeon's post-procedure orders should specify the continuous drainage threshold, how many milliliters of CSF should be drained how quickly when pressure is elevated, as well as a length of time that ICP is above a specified number before draining CSF. Routine drainage options include:

- Open to drainage at a set threshold pressure (continuous)
- Opened in response to ICP elevation (intermittent)

Troubleshooting is required if the monitored ICP waveform changes or is lost and if there is no movement or dripping into the bag of CSF when the tubing is open to drainage. In this situation, surgical attention usually is needed for the possibility of obstruction.

CSF samples should be taken from a port distal to the ventricular catheter. Pushing fluid retrograde (against the direction of CSF flow) through the catheter into the ventricle should only be done when antegrade suction (in the direction of CSF flow) does not clear the line. Only a few milliliters of fluid (1–3) should be flushed through the system into the ventricle to avoid increasing the ICP, especially in cases in which ICP may already be near decompensation on the pressure-volume curve.

EVD catheters that are placed under maximized sterile conditions, with their draining end tunneled under the scalp for a few centimeters, are at low risk for becoming infected and therefore routine sampling of CSF or replacement is not indicated. An EVD should be tapped and CSF sent for protein, glucose, cell count, and culture as part of a fever workup and/or if a patient with an EVD has mental status changes (with or without a new abnormality on head CT).

Antibiotics can be given as prophylaxis during the time the drainage catheter is in the ventricle and brain parenchyma. Current recommendations suggest one dose of periprocedural antibiotics can be considered, but prolonged prophylaxis does not decrease ventriculitis but does contribute to resistant organisms and *Clostridioides difficile* infections. Ventriculitis discovered when tapping an EVD as part of a fever workup, or as part of the workup of altered consciousness, should be treated as aggressively as meningitis is treated.

Even with multiple scalp sutures along its length, ventricular catheters can be pulled out. Patients agitated or too lethargic to cooperate may require sedation and/or restraints to keep them from reaching up and grabbing the EVD tubing. Transport out of the ICU for imaging or procedures in patients with EVDs in place should be avoided unless absolutely necessary. Transfers from the ICU bed to a CT scanner couch should be performed carefully with constant attention to the EVD tubing, dressings, and stopcock.

Clots or air in the tubing can impede or stop flow. When flow stops, with no slowdown in the continuous production of CSF, intraventricular CSF pressure rises rapidly, and the patient begins the progression from alert to unarousable. Daily checks should be done on every EVD and a 24-hour CSF output and ICP mean and spikes should be monitored and tracked.

Accuracy of ICP readings can be problematic if there is significant drift over time. In patients with symptomatic acute hydrocephalus with neurologic signs, management is guided more by clinical response to CSF drainage than by numbers on the monitor.

4. Removal

Once the patient's acute hydrocephalus has been treated and symptoms and signs are resolved, plans should be made to remove the EVD as quickly as possible to prevent infection and transfer the patient out of the ICU.

Based on the etiology of the acute hydrocephalus, the amount of CSF drained daily to keep the patient asymptomatic with an ICP of less than 20 mm Hg without imaging evidence of dilation of ventricles or transependymal edema should be decreasing before removal is considered. EVD occlusion or clamping trials for several hours or days should be conducted. If the patient remains asymptomatic and imaging is unchanged after the EVD clamping trial, the EVD can be discontinued. If, however, with EVD clamping, the patient's symptoms recur or imaging reveals ventricular dilation, then consideration for a permanent internalized drainage system (ventriculoperitoneal or ventriculopleural) will be considered by the neurosurgical team

After an aneurysm is clipped and there is no more bleeding, the red blood cell breakdown debris becomes more dilute with continuing CSF production and the initially red, opaque fluid becomes clear over several days. This clearing of the CSF is frequently associated with a decrease in the amount of fluid drainage required to keep ICP low. If after several days of low or no drainage post-subarachnoid hemorrhage and a CT scan confirms that ventriculomegaly is stable or resolved, the patient can have the EVD safely removed without placement of a VP shunt.

5. Shunt Revision

Many patients with CSF shunts will require revision. A revision can be replacement of one component of the VP shunt, such as the valve, tubing, or ventricular catheter if a focal site of obstruction can be identified, but if the CSF is infected, the entire system should be replaced.

III. INTRACRANIAL HYPERTENSION

Intracranial hypertension is a common neurologic condition in critically ill patients. Increased ICP is a medical emergency due to uncompensated compromise of cerebral perfusion that can result in reduction of oxygen delivery to a critical level in which neuronal function fails and cells die. Rapid intracranial CSF volume reduction is required to prevent irreversible neurologic deficit secondary to injury or death of brain tissue. The physiologic aspect effect is similar to that discussed earlier in the chapter.

The major causes of increased ICP include:

- Obstructive hydrocephalus that commonly occurs after subarachnoid hemorrhage
- Intracranial mass lesions from tumor, hematoma
- Cerebral edema from acute hypoxic ischemic encephalopathy, large cerebral infarction, severe diffuse axonal injury
- Cerebral edema from acute large cerebral infarction (ischemic stroke)
- Severe traumatic brain injury (TBI)/intracranial hemorrhage (subdural, epidural, or intraparenchymal)
- Increased CSF production or decreased production; idiopathic intracranial hypertension as seen in pseudotumor cerebri
- Central nervous system infections like meningitis or encephalitis
- Malignant hypertension

- Obstruction of venous outflow that is seen after venous sinus thrombosis, jugular vein compression, or neck surgery

A. Presentation and Diagnosis

Clinical presentation of patients with high ICP vary according to the underlying cause and acuity of the illness. The global symptoms include headache and decrease level of consciousness. Focal cranial nerve palsies, such as cranial nerve VI and papilledema secondary to congestion, can occur. The mechanism of the Cushing reflex or Cushing's triad, discussed previously, is controversial. However, when present it indicates the need for possible urgent intervention to lower the ICP.

Diagnosis of elevated ICP is usually based on the history, clinical examination, neurologic findings, and sometimes a CT scan of the head. A CT scan of the head should not be used alone to diagnose elevated ICP.

B. Management

Case Study

Consider again the case study presented at the beginning of this chapter: A 42-year-old man with no significant medical history experiences sudden onset of the worst headache of his life during strenuous exercise. The patient is taken to the ED of the local hospital by his family. The ED physician obtains a CT of the head that shows subarachnoid blood over the cerebral convexities and in the left Sylvian fissure. There is a small amount of blood seen in the dependent lateral ventricles with prominence of the temporal horns. Early surgical and neurointerventional consultations are obtained. The GCS score on admission is 11. The consulting neurosurgeon notes that the patient is lethargic. The patient is admitted to the ICU. Measures are taken to maintain adequate blood pressure control, pharmacologic vasospasm prophylaxis, and a four-vessel cerebral angiogram is ordered. The patient has embolization of a right anterior communicating artery aneurysm a few hours after admission.

Upon arrival back to the ICU, he is minimally responsive and vomits. His GCS score is now 6.

- What is the likely diagnosis?
- What diagnostic test will provide further evaluation?
- What treatment is indicated?

The man in this case study likely has acute obstructive hydrocephalus that can be diagnosed with a CT scan of the brain. Treatment will include insertion of an external ventricular drain for ICP monitoring and therapeutic drainage of CSF.

Intracranial hypertension can cause secondary injury in patients with acute neurologic and neurosurgical disorders and may require special neurologic monitoring, including ICP monitoring. A jugular bulb oximeter or brain tissue PO_2 monitor for cerebral oxygen extraction may also be indicated. Monitoring should also include pulse oximetry and capnography to avoid unrecognized hypoxemia and hypo- or hyperventilation.
A ventriculostomy catheter is the preferred device for monitoring ICP. A ventriculostomy catheter can also be used for therapeutic drainage of CSF to reduce ICP. Elevated arterial partial pressure of carbon dioxide (PCO_2) and hypoxemia with an arterial partial pressure of oxygen (PO_2) of less than 50 mm Hg causes vasodilatation and may increase cerebral blood flow. A decreased $PaCO_2$ causes vasoconstriction and reduces cerebral blood flow. An inadequate cerebral blood flow results in brain tissue ischemia and brain tissue death.

If there is a presumed elevated ICP, an ICP monitor should be placed at least for the initial period to monitor the treatments provided, which are not without adverse effects. Indications for an ICP monitor include:

- Glasgow coma scale (GCS) score of < 8
- Diagnosis that needs aggressive management

Goals of therapy include maintaining ICP at less than 20 mm Hg, maintaining CPP greater than 60 mm Hg, and avoiding factors such as anxiety/agitation that precipitate an elevation in the ICP. The best therapy is resolution of the problem that is causing the elevated ICP. Intracranial hypertension is a medical emergency and should be treated as such.

Medical measures for management:

- Elevate the head of bed to reduce ICP, promote adequate CPP, and maximize venous outflow from the head.
- Secure the head in a neutral straight position to reduce excessive flexion or rotation of the neck that may decrease jugular venous drainage.
- Provide sedation and analgesia to reduce metabolic demand, ventilator asynchrony, and sympathetic nervous system responses of hypertension and tachycardia.
- Avoid hyperthermia and maintain euthermia to reduce metabolic demands in the brain.
- Control hypertension to prevent an exacerbation of cerebral edema and decrease the risk of postoperative intracranial hemorrhage. Blood pressure should be sufficient to maintain a CPP > 60 mm Hg.
- Prevent seizures, which increase metabolic demands of the brain.

Medical management of refractory increased ICP:

- Provide heavy sedation and paralysis to reduce ICP by the avoidance of coughing.
- Hyperosmolar therapy with hypertonic saline or mannitol. 1 g/kg of mannitol should be given for an urgent reduction in ICP.
    - Hypertonic saline has an advantage over mannitol in hypovolemic and hypotensive patients.

  - Mannitol is relatively contraindicated in hypovolemic patients because of the diuretic effects.
  - Hypertonic saline augments intravascular volume and may increase blood pressure in addition to decreasing ICP.
- Mild hyperventilation can be used for short periods. Hyperventilation has limited use in the prolonged management of elevated ICP. It may produce a sufficient decrease in cerebral blood flow to decrease ICP and cause brain ischemia by the exact mechanism. It should only be used acutely when herniation is impending to allow time for other treatments or get the patient to surgical intervention.
- Induce barbiturate coma which reduces brain metabolism and cerebral blood flow. Continuous EEG monitoring is used to monitor burst suppression which indicates maximal dosing. This treatment can cause hypotension requiring vasopressor support.
- Corticosteroids are not indicated and have been shown to have a detrimental effect.

Surgical measures for management:

- Perform surgical evacuation of the lesion.
- Drain CSF slowly at a rate of 1 to 2 mL a minute for 2 to 3 minutes at a time until a satisfactory ICP has been achieved. Care should be taken to not over-drain the ventricular system.
- Decompressive craniectomy removes the rigid confines of the skull which circumvents the Monro-Kellie doctrine to improve brain tissue oxygenation.

Please see previous information for further discussion of ICP monitoring, management devices, and implementation.

IV. CEREBRAL VASOSPASM

Case Study

A 65-year-old woman presented to the ED after experiencing the "worst headache of her life." She is diagnosed with a ruptured aneurysm and is admitted to the neuro-intensive care unit by the neurology service. She undergoes embolization of a right anterior communicating artery aneurysm a few hours after her admission. Upon arrival back to the unit, she is minimally responsive and has a large emesis. She undergoes a CT scan of her brain which shows acute hydrocephalus. She undergoes placement of an external ventricular drain and a short time after, her level of consciousness improves. Three days later in her hospital course, however, she becomes less responsive once again.

- What is the likely diagnosis?
- What diagnostic test should she have for further evaluation?
- What treatment is indicated?

The woman in this case study likely has cerebral vasospasm, which can be tested using a transcranial Doppler or angiography. Treatment will include hypertensive, euvolemic therapy and/or transluminal balloon angioplasty and/or intra-arterial infusion of verapamil.

A. Definition and Risk Factors

Cerebral vasospasm is the narrowing of a cerebral blood vessel that results in the reduction of distal blood flow leading to ischemia and cerebral infarction. There are varying degrees of cerebral vasospasm, the worst of which causes a blood vessel to be completely constricted resulting in damage to the brain tissue in that area. It often is a complication of a ruptured brain aneurysm resulting in a subarachnoid hemorrhage, occurring in up to 70% of cases following a subarachnoid hemorrhage. The highest risk occurs 7–10 days following the subarachnoid hemorrhage.

Risk factors include advanced age, poor neurologic function on admission, smoking, hypertension, and genetic factors. There is no difference in the risk of vasospasm between those who have had their aneurysm surgically clipped or endovascularly coiled/embolized. The pathophysiology is not fully understood but is thought to involve structural changes and biochemical alterations of the vascular endothelium and smooth muscle cells. Blood in the subarachnoid space is thought to trigger these changes that result in cerebral vasospasm. Delayed ischemic neurologic deficits occur in about 50% of patients with cerebral vasospasm. This may lead to stroke or death despite aggressive treatment.

B. Clinical Presentation

The diagnosis of cerebral vasospasm is primarily a clinical finding and symptoms typically develop several days to 2 weeks after the initial injury. The frequent use of sedatives in these patients also makes it more difficult to recognize changes in the neurologic examination. Patients at risk for cerebral vasospasm should receive frequent evaluation by the medical and nursing staff in an acute neurologic unit such as that found in a neuro-intensive care unit. Signs and symptoms of cerebral vasospasm may be similar to those seen in patients experiencing a cerebral vascular accident. These include an altered level of consciousness, confusion, or loss of movement in the extremities. Patient may also report a headache or have a fever.

C. Diagnosis

CT scanning is commonly used to evaluate patients who experience signs of neurologic deterioration. A CT scan is also obtained to rule out the development of rebleeding, infarction, or hydrocephalus. Communicating hydrocephalus commonly occurs with subarachnoid hemorrhage, so this needs to be ruled out. Infarcts may be seen on CT in patients that are having cerebral vasospasm, but this is a later finding.

Transcranial Doppler (TCD) measures the velocity of blood flow in the cerebral circulation. TCD detects elevation in the mean cerebral blood flow velocities, primarily in the middle and internal cerebral arteries. The most common locations to be affected by vasospasm include the middle cerebral artery, bilateral anterior communicating arteries, and the terminal vertebral artery or distal branches. Getting adequate windows in some patients can be problematic. Cerebral angiography can be used to diagnose or confirm cerebral vasospasm. Endovascular intervention can be done at the same time.

D. Prevention and Treatment

Cerebral vasospasm accounts for approximately 23% of severe disability and death after a ruptured aneurysm. Nimodipine is a calcium channel antagonist used to prevent cerebral ischemia and is administered at 60 mg oral every 4 hours (30 mg oral every 2 hours if significant hypotension) for 21 days after the aneurysm rupture. This has been found to result in a significant reduction in mortality. Current recommendations for initial management of cerebral vasospasm include induced hypertension and ensuring euvolemia. Hypervolemia and hemodilution, which are components of triple H therapy (hypertension, hemodilution and hypervolemia), are no longer endorsed. Complications of this therapy include volume overload, exacerbation of cerebral edema, and potentially rupturing unsecured aneurysms. Nimodipine is the only treatment that has been shown to provide benefit over multiple studies. Studies using statins and other pharmacologic trials have failed to show benefit.

Endovascular interventions are also likely responsible for the lower incidence of delayed ischemic neurologic deficits. These include transluminal balloon angioplasty and intra-arterial infusion of verapamil. Verapamil reduces the angiographic spasm and has been shown to achieve clinical improvement in a third of cases. Effects may be temporary and the treatment may need to be repeated.

V.NEUROGENIC SHOCK

Case Study

A 27-year-old man is brought to the ED by emergency medical services after diving head-first into a lake. He is awake and states he cannot feel anything below his neck. His vital signs are 80/50 mm Hg, heart rate 66 beats/min, and respirations 20 breaths/min. His breaths are shallow. Clinical examination shows loss of motor and sensation at T4.

- What is the likely diagnosis?
- What diagnostic test should he have for further evaluation?
- What treatment is indicated?

A. Definition

The man in this case study has neurogenic shock syndrome. Neurogenic shock syndrome is dilatory shock state, usually associated with cervical or thoracic spinal cord injuries (above the T6 level). It is thought to be the end result of the impaired autonomic control from loss of sympathetic tone with an intact parasympathetic response. The loss of sympathetic regulation of the vascular smooth muscles of peripheral vessels (vasodilation) results in subsequent pooling of blood in the periphery and decreased contractility leading to decreased cardiac output.

The vast majority of cases of neurogenic shock syndrome are posttraumatic, but it can be associated with non-traumatic insults as well, such as spinal epidurals, malignancies, and abscesses.

B. Clinical Manifestations

The patient presents warm and dry as opposed to the cool clammy presentation of the classic shock patient. There is also an increase in the unopposed vagal tone leading to a relative bradycardia. This affects the patient’s ability to compensate for shock state with tachycardia. It can occur at any time following an insult, but signs and symptoms are typically seen within hours of injury. It is estimated that up to 77% of cervical spinal cord injuries have a component of neurogenic shock (bradycardia), but less than 20% of the injured have the classic presentation. The hemodynamic instability will usually improve over 2 weeks.

C. Management

In the acute phase, judicious fluid resuscitation with crystalloid is suggested. For the trauma patient there may be more than one cause of the patient's hypotension, and all possible causes should be investigated besides the neurogenic source of shock and a careful search to eliminate other potential causes. After the patient has been fluid resuscitated, vasopressors and/or inotropes can be instituted. Care should be used to avoid over-resuscitation with intravenous fluids because pulmonary edema, swelling of the cord, and other untoward injury may occur.

Achieving a MAP of 85–90 mm Hg to maintain adequate perfusion pressure to the spinal cord may be considered controversial by some but is recommended by many guidelines and societies. Using vasopressors to augment the blood pressure would be needed in many instances. For patients with symptomatic bradycardia, atropine may be used. Particularly severe bradycardia may require pacemaker placement.

The term neurogenic shock is often interchanged with spinal shock. However, it should be noted that spinal shock is a completely separate clinical entity. Neurogenic shock refers to the hemodynamic sequelae associated with spinal cord injury. Spinal shock refers to the temporary stunning of the spinal cord and can occur at any level of injury. Patients typically present with a flaccid paralysis and areflexia below the level of injury. The true neurologic examination can be affected. The duration varies from a few days to several weeks. Spinal shock is diagnosed through observation of the bulbocavernous or cremasteric reflexes. If these reflexes are absent, then the patient has spinal shock.

Autonomic dysreflexia (hyperreflexia) is another hemodynamic syndrome associated with spinal cord injury. It typically presents with sudden hypertension. Flushing, headache, and sweating can also be seen. The presentation can vary from an asymptomatic to a potentially lethal event. The pathophysiology of autonomic dysreflexia has not been totally elucidated. It is believed that the massive sympathetic discharge is from impairment of the supraspinal inhibition. Automatic dysreflexia can occur at any time post-injury. The diagnosis is typically made with a systolic blood pressure increase greater than 20 mm Hg above the patient's baseline and bradycardia may also be seen. Autonomic dysreflexia has triggers such as urinary retention and constipation which activate the sequence. It is recommended prior to initiating pharmacologic modalities the following simple steps are performed: place the patient upright, loosen any restrictive clothing or devices, investigate potential bowel or bladder triggers, and search for any other triggers. If the above steps fail to resolve the hypertension, antihypertensive medications may be needed.

VI. DISORDERS OF SODIUM BALANCE DURING BRAIN INJURY

Case Study

A 40-year-old woman is admitted to the hospital with the worst headache of her life. At the time of admission, her neurologic status deteriorates quickly and she now only flexes to pain on the left side and withdraws to deep painful stimuli. The CT scan of the head reveals a large amount of diffuse subarachnoid blood. A cerebral angiogram shows a basilar artery aneurysm that is subsequently successfully coiled. Although her sodium levels were normal on admission, her sodium levels postoperatively gradually decreased daily for the next week from a level of 145 mEq/L to 130 mEq/L.

- What is the likely diagnosis?
- What diagnostic test should she have for further evaluation?
- What treatment is indicated?

A. Secretion of Antidiuretic Hormone (ADH)

Antidiuretic hormone (ADH, also called arginine vasopressin or AVP) is produced in the supraoptic nucleus of the hypothalamus which is then transported and stored in the posterior pituitary and then secreted. Osmoregulation is primarily mediated by osmoreceptors in the anteromedial hypothalamus that are sensitive to small alterations in plasma osmolality. Ideal plasma osmolality for adults is approximately 275–295 mOsm/kg. A decrease in osmolality of 1–2% will suppress ADH levels to promote diuresis. An increase in plasma osmolality will cause water retention. ADH is also released in response to a decrease in circulating blood volume and a significant increase in blood pressure. Syndrome of inappropriate antidiuretic hormone (SIADH), cerebral salt wasting syndrome (CSWS), and diabetes insipidus (DI) all affect the sodium and water balance, but each has a different pathophysiology, diagnosis, and treatment. SIADH is caused by ADH-induced dilutional euvolemic hyponatremia. Central DI results from diminished ADH synthesis or secretion. The etiology of CSWS remains an area of research. The exact mechanism remains open to debate.

B. Hyponatremia

Hyponatremia is a relatively common occurrence in patients with brain injury and in postoperative neurosurgical patients. There are numerous causes of hyponatremia including a variety of neurologic disorders. It is associated with both SIADH and CSWS in neurosurgical patients (**Table 10-1**).

Table 10-1 Causes of SIADH and CSWS

SIADH	CSWS
SAH	SAH
Brain tumors	TBI
Stroke	TB meningitis
ICH	Transsphenoidal surgery
TBI	Metastatic adenocarcinoma of the lung
Postoperative	
Encephalitis	
Inflammatory and demyelinating disorders	
SCI	
Acute intermittent porphyria	
Medications	
• Carbamazepine	
• Opiates	
• Lamotrigine	

Abbreviations: ICH, intracerebral hemorrhage; SAH, subarachnoid hemorrhage; SCI, spinal cord injury; TBI, traumatic brain injury

Case Study

A 63-year-old man is admitted to the hospital for resection of a pituitary adenoma. Postoperatively, his neurologic status is stable, but the serum sodium levels continue to increase daily and his hourly average urine output is approximately 500–600 mL/h.

- What is the likely diagnosis?
- What diagnostic test should he have for further evaluation?
- What treatment is indicated?

1. Clinical Presentation

The signs and symptoms resulting from hyponatremia secondary to SIADH or CSWS are often nonspecific. The rate of decrease in the serum sodium concentration is more important in terms of producing acute symptoms rather than the actual sodium level. However, sodium concentrations <120 mEq/L usually present with acute signs and symptoms such as ataxia, nausea, malaise, muscle cramps, and vertigo. Changes in level of consciousness range from minor changes to lethargy, coma, and seizures. Coma and seizures usually reflect acute changes in the serum sodium level rather than with a slow chronic decrease in sodium.

2. Diagnosis

It can be difficult to distinguish between SIADH and CSWS. Careful attention must be given to the volume status of the patient. SIADH-induced hyponatremia is associated with patients who are euvolemic in contrast to those patients with CSWS who may have significant volume losses and are usually volume depleted. In SIADH in the absence of hypovolemia, hypotension, or adrenal insufficiency, there is impaired urine dilution with urine osmolality values >100 mOsm/kg. A low serum uric acid concentration is often seen in CSWS due to urate wasting in the urine.

3. Treatment

The treatment of choice for SIADH is careful volume restriction. Most patients require fluid restriction to approximately 1 liter per day. In extreme cases of SIADH with very low serum sodium levels and critical acute neurologic changes, hypertonic saline (1.5%, 3%, 23.4% saline) should be used judiciously. Infusion rates of hypertonic saline will depend on the concentration of the hypertonic saline and the desired sodium level. Furosemide and fludrocortisone can be used as adjunct therapy. Vasopressin receptor antagonists (conivaptan and tolvaptan) have also been used in SIADH with normal saline administration to replenish the sodium excreted with diuresis (refer to Chapter 17, Management of Life-Threatening Electrolyte and Metabolic Disturbances for more detailed information). The treatment of CSWS is in contradistinction to SIADH and consists of fluid resuscitation and keeping the patient well hydrated with a positive fluid balance. Intravenous fluids with normal saline or hypertonic solutions may also be used with NaCl oral administration and fludrocortisone as well.

It is important to recognize that too rapid iatrogenic increases or decreases of the serum sodium level by aggressive treatment may result in central pontine myelinolysis (CPM). CPM is a noninflammatory demyelination syndrome that classically affects the central pons but can also affect the midbrain, thalamus, and cerebellum. It is recommended that the sodium level be increased with treatment at <0.5 mEq/L hourly if hyponatremia has been present for >48 hours or the time of decrease is unknown. If the hyponatremia is chronic, rapid correction of sodium (>1 mEq/L/h or 8–12 mEq/L/day) may result in the demyelination syndrome.

C. Hypernatremia

In neurosurgical patients, hypernatremia can result from injudicious use of hypertonic saline solutions but may also result from DI when there is excessive diuresis from water excretion. DI is characterized by large volumes of hypotonic dilute urine (polyuria and nocturia) and polydipsia. In the neurosurgical patient, this is often associated with central DI.

The causes of central DI are a result from damage to the pituitary gland or the hypothalamus. In the postoperative period, DI can be caused by inflammation around the pituitary or the hypothalamus or from damage to these areas intraoperatively. The causes of central DI postoperatively include:

- Subarachnoid hemorrhage
- Intracranial hemorrhage
- Severe traumatic brain injury
- Herniation
- Resection of sellar and pituitary masses

DI associated with neurologic disorders increases both morbidity and mortality. Central DI is secondary to a primary deficiency of ADH. Nephrogenic DI results from an inappropriate response to ADH by the kidneys. Acquired central DI can be seen in a variety of neurosurgical states, such as head trauma, neoplasms, and meningeal and encephalitic infections. DI has been reported to occur in about 75% of postoperative pituitary tumor resections. Most postoperative DI resolves over time although there is a small minority of patients who continue to have persistent DI.

1. Clinical Presentation of Diabetes Insipidus (DI)

Signs and symptoms of hypernatremia are usually nonspecific although gastrointestinal symptoms can occur with nausea and vomiting. Severe signs and symptoms are seen in patients who may be misdiagnosed or diagnosed and treated late and present with signs of extreme volume depletion with lethargy and subsequent coma. Polyuria, nocturia, and polydipsia are commonly seen with central DI.

2. Diagnosis

The diagnosis of central DI should always be suspected in neurosurgical patients, particularly in the postoperative period when diuresis is excessive in relation to fluid intake. When the urine output is excessive, urine studies should be ordered to monitor urine specific gravity, urine osmolarity, and serum sodium levels. In DI, the urine osmolarity is low from 1.000 to 1.005; the urine osmolarity is also low from 50–150 mOsm/L; and the serum sodium is more often elevated in acute neurosurgical patients.

The various clinical parameters can help differentiate among the serum sodium balance etiologies. In SIADH and cerebral salt-wasting etiologies, the serum sodium parameter is low, but it is high in central DI. Urine output is high in CSWS and central DI, but normal or low in SIADH. The intravascular volume status is low in CSWS and central DI, but normal or high in SIADH. CSWS and central DI have low vasopressin levels, but levels are high in SIADH. The most striking difference is seen in the urine sodium parameter, which is high in SIADH, very high in CSWS, but low in central DI.

3. Treatment

Treatment of DI is directed at decreasing urine output by increasing the activity of ADH and replacement of previous and ongoing fluid losses. Fluid replacement for hypernatremia secondary to DI is based on hourly urine output, urine specific gravity, and by calculating the patient’s free water deficit. In addition to oral fluids, additional fluid boluses and maintenance intravenous fluids are often required. It is recommended to begin therapy if the urine output is excessive at >300 mL/h for 2–3 hours or the patient demonstrates any neurologic signs or symptoms (confusion, lethargy, coma).

A low-sodium, low-protein diet can be used in those patients with a milder form of DI. Desmopressin (a synthetic analog of ADH) is recommended for the early treatment of DI. Although oral and nasal spray preparations are available, most neurosurgical patients are treated with doses of 1–2 mcg intravenously or subcutaneously every 12 hours or on a prn basis depending on the sodium level and the urine output.

While therapy is administered, careful monitoring of urine output and sodium levels should be performed, and therapy should be titrated to normal urine output and normal sodium levels. Excessive fluids and injudicious use of desmopressin can lead to water retention and hyponatremia that can result in brain injury and swelling. Although other drugs such as chlorpropamide, carbamazepine, clofibrate, thiazide diuretics, and nonsteroidal anti-inflammatory drugs are available for the treatment of DI, they are less effective than desmopressin and are not often used in the ICU patient.

Key Points

Neurosurgical ICU

- Increased intracranial pressure (ICP) is a medical emergency due to uncompensated compromise of cerebral perfusion pressure (CPP) that can result in reduction of oxygen delivery to a critical level in which neuronal function fails and cells die.
- Acute hydrocephalus is life-threatening and must be drained immediately.
- Cerebral vasospasm should be suspected in a patient with significant subarachnoid blood with new neurologic changes within the first 2 weeks after the initial bleed.

- Most cases of neurogenic shock are posttraumatic and are associated with bradycardia, hypotension, and loss of sympathetic tone.
- Syndrome of inappropriate antidiuretic hormone secretion (SIADH) and cerebral salt-wasting syndrome (CSWS) can be seen in brain-injured patients and postoperatively.
- Diagnosis can be confusing and should be based on urine studies and volume status of the patient.
- Central pontine myelinolysis (CPM) can result from iatrogenic rapid increases or decreases in the sodium level.
- Diabetes insipidus (DI) is often seen after pituitary surgery and the primary goal is to maintain euvolemia and possibly include treatment with desmopressin.

Suggested Readings

1. Carney N, Totten AM, O'Reilly C, et al. Guidelines for the management of severe traumatic brain injury, Fourth Edition. *Neurosurgery*. 2017:80(1): 6-15.
2. Chestnut R, Videtta W, Vespa P, et al. The participants in the international multidisciplinary consensus conference on multimodality monitoring. Intracranial pressure monitoring: fundamental considerations and rationale for monitoring. *Neurocrit Care*. 2014;21 Suppl 2:S64-S84.
3. Diringer, MN, Bleck TP, Hemphil JC et al. Critical care management of patients following aneurysmal subarachnoid hemorrhage: Recommendations from the Neurocritical Care Society's Multidisciplinary Conference, 15:211-240, 2013. www.neurocriticalcare.org.

4. Fried HI, Nwathan BR, Rowe AS, et al. The insertion and management of external ventricular drains: an evidence-based consensus statement: a statement for healthcare professionals from the Neurocritical Care Society. *Neurocrit Care*. 2016;24(1):61-81.

5. Gaasch M, Schiefecker AJ, Kofler M, et al. Cerebral autoregulation in the prediction of delayed cerebral ischemia and clinical outcome in poor-grade aneurysmal subarachnoid hemorrhage patients. *Crit Care Med*. 2018;46(5):774-780.

6. Herrera CAS, Su FB, Backer DD, et al. Treatment of intraparenchymal hypertension with hyperosmotic therapy SH 7.45 vs. M20%. *Crit Care Med*. 2013;41(12):A44.

7. Hinson HE, Stein D, Sheth KN. Hypertonic saline and mannitol therapy in critical care neurology. *J Intensive Care Med*. 2013;28(1):3-11.

8. Kristiansson H, Nissborg E, Bartek J Jr, et al. Measuring elevated intracranial pressure through noninvasive methods: a review of the literature. *J Neurosurg Anesthesiol*. 2013;25:372.

9. Livesay SL, McNett MM, Keller M, Olson DM. Challenges of cerebral perfusion pressure measurement. *J Neurosci Nurse*. 2017;49(6):372-376.

10. Mastantuono JM, Combescure C, Elia N, Tramer MR, Lysakowski C: Transcranial doppler in the diagnosis of cerebral vasospasm: an updated meta-analysis. *Crit Care Med*. 2018;46(10):1665-1672.

11. McMahon D, Tutt M, Cook AM. Pharmacological management of hemodynamic complications following spinal cord injury. *Orthopedics*. 2009;32(5):331.

12. Oiso Y, Robertson GL, Norgaard JP, Juul KV. Clinical review: Treatment of neurohypophyseal diabetes insipidus. *J Clin Endocrinol Metab*. 2013;98(10):3958-3967.

13. Popa C, Popa F, Grigorean VT, et al. Vascular dysfunction following spinal cord injury. *J Med Life*. 2010;3(3):275-285.
14. Ruiz IA, Squair JW, Phillips AA, et al. Incidence and natural progression of neurogenic shock after traumatic spinal cord injury. *J Neurotrauma*. 2018;35(3):461-466.
15. Saindane AM: Recent advances in brain and spine imaging. *Radiol Clin North Am*. 2015;53:477-496.
16. Sterns RH. Disorders of plasma sodium. *N Engl J Med*. 2015;372(13):1269.
17. Sterns RH, Silver SM. Cerebral salt wasting versus SIADH: what difference? *J Am Soc Nephrol*. 2008;19(2):194-196.
18. Verbalis JG, Greenberg A, Burst V, et al. Diagnosing and treating the syndrome of inappropriate antidiuretic hormone secretion. *Am J Med*. 2016;129(5):537.
19. Webb A, Owens S: Subarachnoid hemorrhage. In Hemphill JC, Rabenstein AA, Samuels OB, eds. The Practice of Neurocritical Care. Minneapolis, 2016, Neurocritical Care Society.
20. Zoerle T, Lonbardo A, Colombo A, et al. Intracranial pressure after subarachnoid hemorrhage. 2015;43(1):168-176.

Suggested Websites

1. Hydrocephalus Association. https://www.hydroassoc.org/about-us/newsroom/facts-and-stats-2/
2. www.neurocriticalcare.org.
3. https://www.braintrauma.org/

Chapter 11

LIFE-THREATENING INFECTIONS: DIAGNOSIS AND ANTIMICROBIAL THERAPY SELECTION

Objectives

- Understand and apply the terminology specific to life-threatening infections.
- List the risk factors for the development of infection.
- Identify systemic and site-specific clinical manifestations of life-threatening infections, and understand the diagnostic use of clinical laboratory testing.
- Describe the different clinical and epidemiologic variables used to guide the selection of antimicrobial therapy.
- Outline antimicrobial empiric therapy and treatment of specific infections.

Case Study

A 55-year-old man with diabetes mellitus was transported to the emergency department because of a change in mental status and right arm pain. The wife reported that the patient has been having increasing arm pain with a spreading reddish-colored rash over the arm in the last 24 hours. On awakening, he was found to have a change in mental status with confusion and lethargy. His vital signs at the emergency department show a blood pressure of 90/60 mm Hg, heart rate of 120 beats/min, temperature of 39°C (102.2°F), respiratory rate of 24 breaths/min, and pulse oximetry of 99% on 2-L nasal cannula. The arm is diffusely edematous and erythematous with some areas appearing bruised. You are the responsible caregiver for the patient, and you are admitting the patient to the hospital.

– Does this patient have sepsis?

– What level of care is needed for this patient?

– What initial immediate interventions should be instituted?

I. INTRODUCTION

Life-threatening infections are both a cause and a consequence of critical illness. The incidence of life-threatening infections or sepsis is increasing as a reflection of the growing population of patients at risk: the elderly, immunocompromised patients, and those with malignancy, chronic illness, or multiple trauma. Septic shock, the most severe form of systemic response to infection, is a common cause of death in critically ill adults and children. Early recognition and appropriate management of infections and their sequelae can decrease the mortality rate.

Sepsis is defined as life-threatening organ dysfunction caused by a dysregulated host response to infection. Abnormalities that suggest organ dysfunction may include, but are not limited to, lactic acidosis, oliguria, coagulation disorders, acute alteration in mental status, and an elevated sequential organ failure assessment (SOFA) score. *Septic shock* is a subset of sepsis with circulatory and metabolic/cellular dysfunction associated with a higher risk of mortality. In the clinical setting, septic shock is characterized by hypotension requiring vasoactive drugs to maintain a mean arterial pressure of greater than 65 mm Hg along with a serum lactate level of greater than 2 mmol/L despite adequate fluid resuscitation. Patients with suspected infection who are likely to have a prolonged ICU stay or die in the hospital can be identified at the bedside using the quickSOFA (qSOFA) score which is positive if a patient has two or more of the following: alteration in mental status, systolic blood pressure of less than 100 mm Hg, and a respiratory rate greater than 22 breaths/min.

Given heterogenicity in patient presentation, formal definitions should not be the sole criteria for diagnosis of sepsis and septic shock.

Sepsis definitions were primarily developed for research and quality improvement purposes. Consequently, definitions of sepsis may be difficult to apply to an individual patient. Attempts to use the definitions for individual patients can result in a delayed or missed diagnosis and therapy. There can be no substitute for clinical evaluation by a competent physician to diagnose and initiate management of sepsis and septic shock.

Initial considerations in resuscitation and infection management are described in **Chapters 7** and **8**.

II. DIAGNOSIS OF INFECTION

The diagnosis of serious or life-threatening infection is based on a careful and complete assessment of the patient's history, including risk factors, and the presence of characteristic clinical manifestations. Atypical presentations that may occur, particularly in the elderly and in immunocompromised patients, must also be considered. Laboratory, microbiologic, and imaging results also support the diagnosis of documented or suspected infection.

A. Evaluation of New Fever in Critically Ill Adult Patients

In an era when use of hospital and patient resources is under intensive scrutiny, fevers should be evaluated in a prudent and cost-effective manner. A new fever in a patient in the ICU should trigger a careful clinical assessment rather than automatic orders for laboratory and radiologic tests.

Although some literature defines fever differently, the Surviving Sepsis Campaign has recommend using a value of >38°C (>100.4°F). It is often difficult to determine whether an abnormal temperature is a reflection of a physiologic process, a drug, or an environmental influence. When evaluating a new fever, an attempt should be made to rule out causes other than infection before subjecting the patient to a barrage of investigations. A broad range of medical conditions commonly seen in the ICU can cause fever (usually low grade). These include but are not limited to alcohol or drug withdrawal, transfusion reaction, postoperative fever, adrenal insufficiency, pancreatitis, stroke, pulmonary emboli, and neoplasm. In addition, not all infected patients are febrile. Evaluation should include a review of the patient's chart, a thorough examination and review of all environmental factors as well as drugs (**Table 11-1**) that the patient has received recently, and consideration of physiologic fever that can occur in patients in the ICU, such as postoperative fever. The development of a temperature ≥ 38°C (≥100.4°F) without a clear alternate cause or ≤ 36°C (≤96.8°F) in the absence of a known cause of hypothermia (eg, hypothyroidism, cooling blanket) is a reasonable trigger for a clinical assessment. Clinical evaluation of the patient with fever should guide the requisition of additional laboratory or radiologic studies.

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Fever alone should not routinely trigger blood cultures.

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Table 11-1 Medications Associated With Fever

Common Causes	Uncommon Causes	Rare Causes
Antibiotics	Any other medication	Antibiotics
Beta-lactams		Aminoglycosides
Sulfonamides		Tetracyclines
Nonantibiotics		Macrolides
Sulfa-containing drugs		Clindamycin
Stool softeners		Chloramphenicol
Diuretics		Vancomycin
Sleep medications		Aztreonam
Antiseizure medications		Quinolones
Antidepressants/tranquilizers		Carbapenems
Antiarrhythmics		Tigecycline
NSAIDs (nonsteroidal anti-inflammatory drugs)		Daptomycin
Opiates		Quinupristin/dalfopristin
		Linezolid
		Nonantibiotics
		Digoxin
		Steroids
		Diphenhydramine
		Aspirin
		Vitamins

Reproduced with permission Cunha BA. Clinical approach to fever in the neurosurgical intensive care unit: Focus on drug fever. *Surg Neurol Int*. 2013;4(Suppl 5):S318-S322. Copyright 2013 Cunha BA.

In the ICU, body temperature is most accurately measured by an intravascular, esophageal, or bladder thermistor, followed by rectal, oral, and tympanic membrane measurements. Axillary measurements, temporal artery estimates, and chemical dot thermometers should not be used in the ICU. Rectal thermometers should be avoided in neutropenic patients.

The diagnosis of drug-induced fever is usually established by the temporal relationship of the fever to starting and stopping the drug. Patients can be rechallenged with the drug to confirm the diagnosis, but this is rarely done unless the drug in question is essential and alternatives are not available. Patients developing anaphylaxis or toxic epidermal necrolysis as a result of drug exposure should not be rechallenged.

Fever is a common phenomenon during the initial 48 hours after surgery. Fever in this early postoperative period is usually noninfectious in origin, presuming that unusual breaks in sterile technique or pulmonary aspiration did not occur. However, 96 hours after surgery, fever is more likely to represent infection.

Surgical site infections alone account for approximately 25% of overall costs related to treatment of nosocomial infections. The rate of surgical site infection is approximately 3%. This rate varies based on the degree of contamination of the incision, the patient's medical comorbidities (eg, diabetes mellitus and obesity increase risk), whether surgery is prolonged or an emergency, and whether any antimicrobial prophylaxis is administered correctly (eg, appropriate narrow spectrum of activity, administration just before incision, and discontinuation within 24 hours [48 hours for cardiac surgery]).

B. Epidemiologic Factors

Serious or life-threatening infections may occur in patients from the community, long-term care facilities (ie, nursing homes), or hospital settings. Serious or life-threatening community-acquired infections include bacterial pneumonia, central nervous system (CNS) infections or meningitis, urosepsis, intra-abdominal sepsis caused by a ruptured or obstructed viscus, or sporadic uncommon infections, such as necrotizing fasciitis. Patients from long-term care facilities share this spectrum but often have infections with more resistant pathogens. Patients from long-term care facilities have an increased risk of developing device-related infections and/or infected decubitus ulcers. Finally, hospitalized patients are exposed to antimicrobial-resistant flora and numerous invasive devices, in addition to having more comorbidities and greater severity of illness than the other populations, making them prone for the development of sepsis.

Healthcare-associated infections are acquired while the patient is receiving treatment for other conditions within a healthcare setting. They are of particular importance because of the higher risk of resistant pathogens. It is estimated that healthcare-associated infections result in almost 100,000 deaths annually in the United States. Infection can be acquired during the current hospitalization or may be associated with an admission in the preceding 60 days. In addition, other forms of healthcare-associated infection include the development of infection in residents in a nursing home or extended-care facility and patients receiving home intravenous antibiotic therapy or chemotherapy, chronic dialysis, and/or home wound care.

C. Predisposing Conditions

The presence of predisposing conditions should alert the care team to patients at higher risk of developing infections, including some infections that may be associated with a particular predisposing condition (**Table 11-2**). Permanent prosthetic implants, such as heart valves, intravascular grafts, or orthopedic devices, may become infected in either the early or late postoperative period. Invasive procedures (eg, surgery, vascular catheterization, placement of urinary catheters, and endotracheal intubation) breech the normal mucosal defense barriers and predispose patients to infection. Healthcare providers need to remember that the lack of predisposing conditions does not eliminate the possibility that a serious infection is present.

Table 11-2 Conditions Predisposing to Infection

- Extremes of age
- Transplant recipients
- Multiple trauma
- Alcoholism
- HIV
- Chemotherapy
- Absence of spleen
- Invasive procedures/devices
- Diabetes mellitus
- Hepatic failure
- Malnutrition
- Malignancy
- Corticosteroid use
- Burns
- Prosthetic implants
- Neutropenia

D. Clinical Manifestations

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Hypothermia predicts poor outcome in serious infections.

The clinical manifestations of life-threatening infections are diverse, and they may be subtle or overt, and localized or systemic. An awareness of the signs and symptoms associated with specific infections allows early recognition and prompt institution of appropriate empiric antimicrobial and supportive management. However, most of the clinical manifestations are not specific.

1. Systemic Signs and Symptoms

Fever is the most frequent systemic manifestation of infection, but patients with serious infections may be normothermic or even hypothermic. Hypothermia is more frequently seen in the elderly; those with physical debilitation/nutritional impairment, alcoholism, and hepatic or renal failure; and with the use of antipyretic medications/steroids. Severe or prolonged septic shock will often present with marked hypothermia. Temperature probes on a urinary catheter, when available, are the most reliable methods to measure the core temperature. Temperature measurement is most practically obtained via the oral or rectal routes, although the limitations of each method should be considered.

Other systemic manifestations include chills, rigors, hypotension, tachypnea, dyspnea, tachycardia, and nausea and vomiting. Tachycardia is almost always present but may be absent in the presence of cardiac conduction disturbances, autonomic dysfunction, β-blockers or calcium channel blockers, and drug fever. Hypotension may be the result of dehydration and hypovolemia but may also indicate septic shock, particularly if the blood pressure does not respond well to volume resuscitation. Hypoperfusion of the kidneys may result in oliguria or anuria. Encephalopathy is a common clinical manifestation and ranges from lethargy/irritability to delirium and coma. Petechiae and/or ecchymosis may be present, particularly on distal extremities.

2. Site-Specific Signs and Symptoms

Some signs and symptoms of infection could be associated with the specific source of infection:

- Infections of the CNS may be associated with headache, seizures, meningismus, or focal neurologic findings. Altered mental status is often present but not specific for CNS infections.
- Diffuse or localized respiratory tract infections may be associated with dyspnea, tachypnea, cough, sputum production, or (rarely) hemoptysis. Chest auscultation findings, such as crackles, rhonchi, or tubular breath sounds, indicate whether the process is localized or diffuse. Diminished breath sounds and dullness on percussion are suggestive of a pleural effusion.
- Intra-abdominal infections may cause abdominal pain, abdominal distension, nausea and/or vomiting, diarrhea, and anorexia. Diaphragmatic irritation can be perceived as pain in the side of the neck and proximal shoulder area or may cause hiccups. Findings on examination may include diffuse or local tenderness, rebound tenderness, ileus, or guaiac-positive stool. A wound infection with evidence of fascial disruption may signal an intra-abdominal infection below the fascia.
- Urinary tract infections may produce flank pain or abdominal pain, tenderness, dysuria, hematuria, and oliguria. Typically, a urinary catheter–associated infection does not produce localized symptoms.
- Cutaneous manifestations may result from a primary infection of the skin or skin structures (eg, pain, erythema, and induration as a result of cellulitis; wound margin erythema; tenderness or purulent discharge; vesicular lesions caused by herpes infection) or be a consequence of disseminated systemic infection (eg, erythematous indurated papules or nodules of ecthyma gangrenosum caused by bacteremia, septic emboli caused by infective endocarditis, diffuse macular erythema caused by toxic shock syndrome, distal symmetric purpura fulminans caused by meningococcemia). Necrotizing soft-tissue infections can exhibit skin discoloration (progressing from red to purple on to almost black), bullae with hemorrhagic or dark fluid, and crepitus.

E. Laboratory Manifestations

Routine laboratory tests are not specific in the diagnosis of life-threatening infections but may be suggestive and allow assessment of organ function. The white blood cell (WBC) count is usually elevated with a shift of neutrophils to more immature forms (called a *left shift*). Toxic granulation and Dohle bodies are often observed in such neutrophils during severe infections, particularly with septic shock. Leukocytosis is commonly seen in noninfectious processes, such as the early postoperative period, corticosteroid therapy, massive transfusions, and polytrauma. Conversely, a normal leukocyte count may be observed despite active infection in the elderly and in patients with hypersplenism or chronic myelosuppressive disorders. Neutropenia may result from overwhelming bacterial or fungal infection and septic shock (especially in the nutritionally deficient, alcoholics, and AIDS patients), severe viral infection, typhoid fever, brucellosis, and other infections. Like an altered WBC count, elevated procalcitonin and C-reactive protein typically indicate ongoing inflammation/infection.

One of the most common coagulation abnormalities in sepsis is isolated thrombocytopenia. A modest decline in platelet count may be a subtle, early clue to the presence of infection. Platelet count nadir usually occurs within 4–7 days of septic shock presentation. Prothrombin time is often elevated at admission with severe infections, including septic shock. Overt disseminated intravascular coagulation is a less common finding but is a poor prognostic sign. It is characterized by elevations in prothrombin time, partial thromboplastin time, fibrin split products, and/or D-dimer, and decreased fibrinogen.

F. Clinical Manifestations

Sepsis is often associated with organ dysfunction at presentation. Apart from cardiovascular collapse associated with septic shock, overt organ dysfunction can involve the brain, kidneys, and liver among other organs. The cardiovascular collapse results in an elevated serum lactate level as a consequence of compromised oxygen delivery to the tissues. Tachycardia to increase cardiac output is one of the first compensatory mechanisms noted in clinical examination. Skin will be warm and flushed during early stages of septic shock but can progress to cold/clammy if source control is not obtained. Vasodilation, in addition to capillary leak from immunologic response, results in intravascular volume depletion which contributes to hypoperfusion associated with septic shock.

Hypoperfusion of the kidneys results in an elevated serum creatinine and urea with decreased urine output. If perfusion is not restored in a timely manner, the patient can progress to an acute tubular necrosis resulting in the need for renal replacement therapy. Strict measurement of urine output with a goal of 0.5 mL/kg/h should be completed along with trending of serum urea/creatinine levels.

Early liver injury caused by sepsis-associated hypoperfusion will typically manifest as modest elevations of transaminases. Severe shock, however, is often associated with markedly elevated transaminases and hepatic necrosis as a result of shock liver or ischemic hepatitis. With respect to the liver, persistence of sepsis will usually result in a cholestatic picture with elevated bilirubin with or without a mild elevation of transaminases by the second week.

Initial arterial blood gas measurements usually reflect a respiratory alkalosis as a result of inflammatory stress-related tachypnea attempting to compensate the metabolic acidosis produced by the elevated tissue lactate levels. Persistence of sepsis can ultimately lead to adult respiratory distress syndrome (ARDS).

A relatively underappreciated early marker of sepsis is hyperglycemia resulting from inflammatory cytokine-driven insulin resistance. In contrast, prolonged severe septic shock may demonstrate hypoglycemia because of depletion of hepatic glycogen stores.

G. Microbiologic Studies

Microbiologic studies are divided into those with immediately available results (minutes to a few hours) and those requiring a period for incubation or laboratory determinations. Among the studies with quickly available results is

Gram stain of body fluids. Special stains (such as fungal and acid-fast stains), immunoassays (such as urine *Legionella* antigen and *Clostridioides difficile* toxins), and immunoelectrophoresis panels require time to process.

Empiric antimicrobial therapy for the patient with a presumptive life-threatening infection should be initiated based on clinical and epidemiologic clues.

Ideally, all cultures should be obtained before initiation or modification of antimicrobial therapy, but this may not be possible in a patient who is rapidly deteriorating. The selection of culture site(s) should be guided by clinical manifestations. Indiscriminate sampling from many sites not only may yield misleading results because of culture contamination or site colonization, but is also not cost-effective and may pose additional risks to the patient. Repeat cultures may be appropriate to assess for changes in the type of organism or resistance patterns.

At least two sets of peripheral blood cultures (aerobic and anaerobic bottles) should be obtained from at least two, preferably three, different anatomic sites. A blood volume of 10 to 15 mL per culture set is optimal in adults. The volume of blood, number of cultures, and technique are more important factors for detection of bacteremia than timing of culture collection. Fever at the time of blood culture collection is neither sensitive nor specific for the presence of bacteremia. Obtaining blood cultures from indwelling peripheral or central intravascular catheters may yield false-positive results because of microbial contamination of the catheter hub. Isolator blood cultures may improve the diagnostic yield for some organisms (eg, *Candida*, *Mycobacterium*) or in patients already receiving antimicrobial therapy; cost-effectiveness, however, is unclear.

Respiratory tract cultures require expectorated sputum from the nonintubated patient and tracheal suction or bronchoscopy specimens from an intubated patient. Many microbiology laboratories will screen the specimen for the number of epithelial cells and neutrophils to determine adequacy for culture. Expectorated sputum samples can be unreliable for help in identifying bacterial or fungal infections because oftentimes they are not a good sample. Quantitative cultures of lower respiratory tract secretions obtained by bronchoscopy can assist with discriminating between colonizing and pathogenic bacteria.

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Do not send endotracheal tube tip or Foley catheter tip for culture.

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In the absence of catheterization, urine cultures should be clean-catch voided specimens; in catheterized patients, specimens should be aspirated from the urinary catheter tubing. If the catheter has been in place for few days, replacement is recommended and the culture should be obtained from the new catheter. Thresholds for significance differ for clean-catch urine ($>10^5$ organisms/mL) and catheter-obtained urine ($>10^3$ organisms/mL). Urinalysis for the detection of pyuria will help to discriminate bacteriuria from cystitis or upper tract infection. It is not recommended to send endotracheal tube tip or Foley catheter tip for culture.

If there is a suspicion of intravascular catheter infection, the catheter should be removed in an aseptic fashion (by applying chlorhexidine to the surrounding skin and external part of the catheter adjacent to the skin exit). Do not routinely send catheter tip for culture. Clinical correlation between blood culture(s) and appearance of the catheter exit site is required to discriminate between catheter-related bacteremia and local catheter-related infections. The most reliable method for diagnosis of intravascular catheter-related bloodstream infections is the quantitative assay of paired cultures from peripheral and catheter blood samples. Few institutions perform this routinely because of resource requirements. An alternate approach is to examine the difference in time to culture positivity between the paired cultures with a more rapid positivity being seen in samples drawn from an infected catheter.

III. ANTIMICROBIAL THERAPY

Case Study

A 65-year-old man was admitted for altered mental status. He was found down at home by his wife. He was in his normal state of health the day prior. On physical examination, the physician noted a fever, nuchal rigidity, and photophobia. A lumbar puncture is performed and his laboratory studies confirm meningitis. You are asked to evaluate him.

- What is the likely source of this patient's infection?
- What factors would influence your choice of antimicrobial agent?

A quick, highly targeted initial assessment, immediate resuscitation, and rapid initiation of empiric antimicrobial therapy are co-priorities in the management of hemodynamically unstable patients with a severe, life-threatening infection. Refinements to therapy can be implemented following a more detailed evaluation of the patient's history, physical examination, and auxiliary test results (laboratory and imaging studies).

Early source control (suspected source of infection) is paramount to favorable outcomes and is an essential adjunct to adequate antimicrobial therapy. Examples of source control include wound debridement, percutaneous or surgical drainage of a closed-space infection, foreign body removal, and surgery. The antimicrobial therapy recommendations found in this chapter are general guidelines only. For each clinical scenario, antimicrobial choices must be individualized to match the clinical manifestations, patient history of previous antibiotic exposure, patient history of infection along with organism/susceptibilities, and the available epidemiologic and microbiologic information, including the patterns of microbial prevalence and resistance in the institution or local community.

Early use of appropriate empiric antimicrobial therapy reduces infection-associated mortality.

The selection of appropriate antimicrobial therapy depends on the following factors:

1. The suspected microbial pathogen(s) and site of infection: The most common sites for life-threatening infections in adult patients involve the lower respiratory tract, the intra-abdominal cavity, and the bloodstream. Rapidly progressive soft-tissue infections and CNS infections should also be considered and are often clinically obvious. Antimicrobial penetration to the site of infection should also be considered. The CNS and lungs are two sites that allow limited penetration of certain antimicrobials; therefore, the pharmacokinetic characteristics of the selected agents must be understood to ensure maximal antimicrobial activity at those sites.

2. Gram stain results of available specimens from the suspected site: The description of early stain results may help direct the clinician to the broad categories of organism(s) that should be covered. Examples include gram-positive cocci in clusters (staphylococci) or pairs and chains (enterococci, streptococci), lancet-shaped diplococci (pneumococcus), gram-positive bacilli (*Corynebacterium*, *Nocardia*), gram-negative bacilli (Enterobacteriaceae, *Escherichia coli*, *Klebsiella*, *Pseudomonas*), small pleomorphic gram-negative bacilli (*Bacteroides* spp), gram-negative coccobacilli (*Haemophilus* spp, *Moraxella*, *Acinetobacter*), and yeast (*Candida*). However, the clinician should wait for final culture and sensitivity results before de-escalating to narrowly targeted antimicrobial therapy.

If the source of infection is not obvious on initial examination, reconsider the possibility of the lungs or abdomen as the source.

3. Assessment for antimicrobial resistance: Factors predicting that a particular bacterial pathogen may be resistant to a wider range of antimicrobials include the following:
    - Prior isolation of resistant strains from the same patient
    - Prior antimicrobial therapy (broad-spectrum antimicrobial therapy such as antipseudomonal penicillin/β-lactamase inhibitor combinations, third- and fourth-generation cephalosporins, fluoroquinolones, carbapenems, vancomycin)
    - Extended hospital or ICU stay
    - High endemic rate of multidrug-resistant bacteria in the institution or ICU (eg, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant *Enterococcus*, multidrug-resistant *Pseudomonas*, *Stenotrophomonas*, carbapenem-resistant enterobacteriae (CRE), extended-spectrum β-lactamase (ESBL) enterobacteriae)
    - Ongoing epidemic outbreak in the hospital or ICU
    - Long-term dialysis
    - Residence in a nursing home or extended-care facility
    - Immunosuppressive diseases or therapy

Certain common organisms have become increasingly resistant to formerly effective antimicrobials. This category includes

Streptococcus pneumoniae with intermediate- and high-level resistance to penicillin and ceftriaxone, *Enterococcus faecium* strains resistant to ampicillin and vancomycin, *S aureus* resistant to oxacillin/methicillin (methicillin-resistant S aureus [MRSA]), gram-negative bacilli (*E coli*, *Klebsiella pneumoniae*) with extended-spectrum β-lactamase or chromosomal-mediated β-lactamase production observed in strains of *Pseudomonas aeruginosa*, carbapenemase-producing Enterobacteriaceae or other mechanisms of multiple resistance to broad-spectrum antimicrobial therapy. It is vital to know and update the resistance pattern of the different bacterial pathogens in each institution and each ICU. Most institutions will have an antibiogram that shows the resistance patterns in the institution.

4. Comorbid conditions: Less nephrotoxic antimicrobials may be preferable in patients with diminished renal function or patients at risk for renal failure unless the benefit of use outweighs the risk of renal dysfunction. Other comorbidities to consider include bone marrow suppression, chronic or acute liver failure, prior hearing deficits, pregnancy, and a history of major hypersensitivity or other strong adverse reactions to a specific antimicrobial.

IV. RECOMMENDED ANTIMICROBIAL THERAPY

Prudent antimicrobial therapy involves early initiation as well as suitable de-escalation.

The use of the antimicrobial therapies recommended here is based on the suspected site of infection in the absence of culture results. The clinician should always consider the dose, dose adjustments, possible interactions, and adverse effects of selected agents. Antimicrobial therapy should be given in maximum appropriate therapeutic doses. The celerity on the administration of the appropriate antimicrobials following clinical diagnosis has been shown to be a critical determinant of outcome in a variety of severe infections including meningitis, community-acquired pneumonia, and septic shock. In critically ill patients, intravenous administration is preferred to intramuscular or oral routes. Oral dosing of antimicrobials with similar bioequivalence (eg, fluoroquinolones) and adequate gastrointestinal absorption may be substituted after the patient stabilizes and is able to take medication by mouth or via feeding tube. Dosage adjustments must be made for the elderly, neonates, children, and patients with renal or hepatic dysfunction. Antimicrobial de-escalation should be implemented in appropriate clinical situations once cultures are negative or a specific organism and antibiotic susceptibilities are identified. In the treatment of infection, antimicrobial agents must be used appropriately and responsibly. A list of selected site infections with empiric antibiotic therapy is found in **Table 11-3**. Source control is a critical element of treatment for a variety of severe infections found in the ICU, including empyema, abdominal sepsis (eg, ischemic bowel, bowel perforation, volvulus, ascending cholangitis, and cholecystitis), pyelonephritis associated with ureteral obstruction, necrotizing soft-tissue infections, wound infections, decubitus ulcers, and vascular central line-associated blood stream infections (CLABSI).

Table 11-3 Site Infections and Empiric Antibiotic Therapies

Suspected Site of Infection	Possible Organism	Initial Empiric Antibiotics	Dose
Severe intra-abdominal infection (non-biliary)	*Pseudomonas*, extended spectrum β-lactamase-producing Enterobacteriaceae, *Acinetobacter*, multidrug-resistant GNB, *Bacteroides* spp	Imipenem-cilastatin, meropenem, or piperacillin-tazobactam or combination of cefepime and metronidazole	Imipenem-cilastatin, 500 mg IV every 6 h Meropenem, 1 g IV every 8 h Piperacillin-tazobactam, 4.5 g IV every 6 h Cefepime, 2 g IV every 8 h Metronidazole, 500 mg IV every 8 h
Urinary infection	*Escherichia coli, Pseudomonas aeruginosa*, and other GNB	Ceftriaxone or piperacillin-tazobactam	Ceftriaxone, 1 g IV daily Piperacillin-tazobactam, 4.5 g IV every 6 h
Lower respiratory infection	*P aeruginosa, E coli, Klebsiella pneumoniae, Acinetobacter* and other GNB spp, GPC like MRSA	Cefepime or carbapenem; vancomycin added whenever MRSA is considered	Cefepime, 2 g IV every 8 h Meropenem, 1 g IV every 8 h Vancomycin, 1 g IV every 12 h
Necrotizing soft tissue infection	Usually multi-microbial, GPC, GNB, and anaerobes	Vancomycin plus cefepime or carbapenem, and clindamycin	Cefepime, 2 g IV every 12 h Meropenem, 1 g IV every 8 h Clindamycin, 600 mg IV every 8 h Vancomycin, 1 g IV every 12 h
Gastrointestinal tract	*Clostridioides difficile*	Metronidazole PO or IV, and vancomycin PO or rectally (if ileus)	Cefepime, 2 g IV every 12 h Meropenem, 1 g IV every 8 h Clindamycin, 600 mg IV every 8 h Vancomycin, 1 g IV every 12 h Vancomycin, 125 mg by mouth every 6 h Fidaxomicin, 200 mg by mouth twice a day
Meninges, bacterial infection	*Streptococcus pneumoniae, Neisseria meningitidis, Listeria, Staphylococcus aureus*, and GNB following procedures (eg, shunt placement)	Ceftriaxone for *S pneumoniae*, ampicillin for *Listeria*, cefepime and vancomycin for others	Ceftriaxone, 2 g IV every 12 h Ampicillin, 2 g IV every 4 h Cefepime, 2 g IV every 8 h Vancomycin, 1 g IV every 12 h

Abbrevitions: GNB, gram-negative bacilli; GPC, gram-positive cocci; MRSA, methicillin-resistant *S aureus*. PO, by mouth.
Data taken from Lexi-Comp. Wolters Kluwer. 2020.

A. Central Nervous System

1. Meningitis

Bacterial meningitis causes one of the crucial emergencies. When it is suspected clinically, antimicrobial therapy should be instituted immediately, within 60 minutes, without waiting for the results of a lumbar puncture. Community-acquired acute bacterial meningitis in adults is most commonly caused by *S pneumoniae* or *Neisseria meningitidis*, and initial empiric therapy with a third-generation cephalosporin (ceftriaxone or cefotaxime) provides adequate empiric coverage, with vancomycin added if penicillin-resistant *S pneumoniae* is suspected or confirmed. If *S pneumoniae* is isolated, a third-generation cephalosporin should be continued until penicillin sensitivity is confirmed, at which point the patient should be switched to high-dose penicillin G. *N meningitidis* in cerebrospinal fluid (CSF) or blood culture should be treated with high-dose parenteral penicillin G. If *N meningitidis* is isolated, healthcare workers with significant exposure require antimicrobial prophylaxis. In addition to antimicrobial therapy, adjunctive dexamethasone (0.15 mg/kg intravenously every 6 hours for 2–4 days) is also recommended to decrease the risk of morbidity and mortality, particularly in pneumococcal meningitis.

Special circumstances require different empiric antimicrobial coverage. *Listeria monocytogenes* may be a cause of bacterial meningitis in extremes of age (neonates, infants, and the elderly) and in patients with T-lymphocyte defects, usually associated with diabetes mellitus, corticosteroid use, and immunosuppressive therapy (eg, organ recipients and patients with autoimmune disease). Patients with suspected *Listeria* meningitis should receive ampicillin (trimethoprim-sulfamethoxazole in the patient with penicillin allergy). Those patients who have undergone recent neurosurgical procedures or placement of CSF shunts are at increased risk for *S aureus*, coagulase-negative staphylococci, and gram-negative bacilli (*Pseudomonas*, *Klebsiella*). Therefore, such patients require initial empiric antimicrobial coverage with high-dose vancomycin and a third- or fourth-generation cephalosporin. If methicillin-susceptible *S aureus* (MSSA) is confirmed, nafcillin is the drug of choice.

Meningitis presenting in a subacute fashion over several weeks or longer, with predominance of CSF lymphocytes, is more likely to occur in immunocompromised patients. Pathogens such as *Mycobacterium tuberculosis*, *Toxoplasma gondii*, and *Cryptococcus neoformans* should be considered in this setting.

2. Encephalitis or Meningoencephalitis

Many viral agents can cause encephalitis or meningoencephalitis, but only herpes simplex (HSV) and cytomegalovirus (CMV) encephalitis are amenable to therapy. Herpes simplex encephalitis usually occurs in immunocompetent individuals presenting from the community. This is considered an emergency. Fever, lethargy, confusion, and seizures are the most common presenting signs and symptoms. Hemorrhagic CSF and temporal lobe involvement on imaging studies (computed tomography or magnetic resonance imaging) or electroencephalography are suggestive of HSV encephalitis. Polymerase chain reaction testing of CSF is sensitive for diagnosis of this infection. If HSV encephalitis is suspected or confirmed, a 14- to 21-day course of parenteral acyclovir should be initiated promptly, pending further studies. CMV encephalitis usually occurs in patients with suppressed immune status (HIV and transplant patients) and could have the same clinical manifestations as HSV encephalitis. Polymerase chain reaction testing of CSF for CMV is also highly sensitive, and therapy should include ganciclovir or foscarnet.

3. Brain Abscess

Brain abscess is an uncommon infection but should be suspected in patients with chronic infections of parameningeal structures, left-sided endocarditis, or congenital cyanotic heart disease. Brain abscesses also have been associated with immunosuppression, as in patients with AIDS, intravenous drug abusers, or transplant recipients. Infections are often polymicrobial, and etiologic organisms include aerobic and anaerobic streptococci, staphylococci, gram-negative bacteria, and anaerobes. Initial antimicrobial therapy should include vancomycin, high-dose metronidazole, and a third-generation cephalosporin (ceftriaxone). In patients at high risk for toxoplasmosis (eg, those with AIDS, cardiac transplant recipients), pyrimethamine/sulfadiazine should be part of the initial antimicrobial regimen. Less common causes of brain abscess include tuberculosis, nocardiosis, syphilis, amoeba, and other parasites. The diagnostic yield of CSF cultures for brain abscess is extremely low, and brain biopsy may be needed in patients who fail to respond to empiric therapy.

B. Respiratory Tract

1. Severe Community-Acquired Pneumonia (Immunocompetent Host)

The most common organism resulting in hospitalization for community-acquired pneumonia is *S pneumoniae*, but other causative organisms include *Legionella*, *Mycoplasma*, and *Chlamydia*. *Haemophilus influenzae* is an uncommon pathogen in the United States because of the introduction of the vaccine against *H influenzae* type B in children. A β-lactam (ceftriaxone, cefotaxime, ampicillin-sulbactam) plus either a macrolide (azithromycin) or a respiratory fluoroquinolone (moxifloxacin, gemifloxacin, or levofloxacin) are recommended in patients admitted to the ICU. The CURB-65 Score can be used to determine the need for hospitalization as well as placement in the ICU. If the patient is allergic to penicillin, a respiratory fluoroquinolone and aztreonam are recommended. If aspiration pneumonia is suspected (alcoholic patients, presence of poor dentition), the addition of clindamycin is warranted unless a β-lactam/β-lactamase inhibitor combination is used. If *Pseudomonas* is a consideration, an antipseudomonal β-lactam (piperacillin-tazobactam, cefepime, imipenem, or meropenem) should be used. Vancomycin or linezolid may be added if community-acquired MRSA is suspected.

2. Community-Acquired Pneumonia (Immunocompromised Host)

Immunocompromised patients with pneumonia may have the same pathogens as an immunocompetent host but with more severe infection. Radiographic evidence of interstitial pneumonia or a normal chest radiograph in a patient with prominent respiratory symptoms who has T-cell deficiency (AIDS, chronic steroid use) should prompt the addition of trimethoprim-sulfamethoxazole in appropriate doses for possible *Pneumocystis jirovecii* (formerly *carinii*). Consider the addition of steroids in *P jirovecii* pneumonia associated with significant hypoxemia. Focal lesions (eg, abscess, nodules) are suggestive of fungal infections, *M tuberculosis*, or *Nocardia*; empiric coverage with antifungal agents, anti-mycobacterial agents, and trimethoprim-sulfamethoxazole may be warranted in these circumstances. Patients with suspected *M tuberculosis* infection also require respiratory isolation. CMV or other viral infection also should be considered in the differential of an interstitial pneumonitis.

3. Nosocomial and Ventilator-Associated Pneumonia

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Use short courses of antimicrobial therapy when appropriate.

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Gram-negative organisms and *S aureus* are frequent causes of pneumonia in hospitalized patients or those who require mechanical ventilation. Nosocomial organisms tend to be more resistant and are more likely to be present in patients with extended hospital stays, prior antimicrobial therapy, and comorbidities. If possible, attempts should be made to obtain lower respiratory tract samples for quantitative microbiologic evaluation in mechanically ventilated patients. Adequate antimicrobial coverage can usually be provided with a third- or fourth-generation cephalosporin, β-lactam/β-lactamase inhibitor combinations, or a carbapenem, plus an anti-pseudomonal fluoroquinolone (ciprofloxacin, moxifloxacin, or levofloxacin) or an aminoglycoside. If *Pseudomonas* is a consideration, an antipseudomonal β-lactam (piperacillin-tazobactam, cefepime, imipenem, or meropenem) should be used. Therapy with trimethoprim-sulfamethoxazole should be included if the possibility of *Stenotrophomonas maltophilia* is suspected or confirmed. Vancomycin should be considered if methicillin-resistant *S aureus* is a possible pathogen. Pneumonia caused by methicillin-sensitive strains of *S aureus* should be treated with an anti-staphylococcal penicillin because these agents are superior to vancomycin. Patients with methicillin-resistant *S aureus* who are vancomycin-intolerant or are not responding to vancomycin may be treated with linezolid. If vancomycin is used, serum trough levels should be maintained no lower than 15 to 20 μg/mL because lung penetration of this agent is limited. Shorter courses (8 days) of therapy may be appropriate as long as non-lactose fermenting organisms are not isolated. Consideration may be given to stop the antibiotic therapy if the lower respiratory tract cultures are negative.

C. Heart

Infections of the heart are usually severe and life-threatening and require coordinated medical care with a cardiologist and sometimes with a cardiovascular surgeon. Microbiologic studies and echocardiography (transthoracic or transesophageal) are the cornerstones for the diagnosis and management of any infection in the heart.

Infective endocarditis, or infection of the endocardial surface of the heart, most frequently involves the heart valves. Intravenous drug abuse, prosthetic valves, sclerosing of natural valves as a result of aging, hospital-acquired infections, and newly identified pathogens (*Bartonella* spp, *Coxiella burnetii*, *Tropheryma whipplei*, fungi) are the main risk factors for this condition. Demonstration of bloodstream infection and positive echocardiographic evidence of valvular vegetations are key to making the diagnosis, although peripheral embolic phenomena and other findings are strongly suggestive. Gram-positive cocci, mainly *Staphylococcus* and *Streptococcus*, but also *Enterococcus*, are the most common microorganisms isolated in infective endocarditis in the general population and in specific risk groups (intravenous drug users and prosthetic valve endocarditis), but gram-negative, polymicrobial, fungal, and culture-negative cases of endocarditis are becoming more common. Bactericidal antimicrobial therapy (eg, penicillins/third-generation cephalosporins, daptomycin with or without an aminoglycoside, glycopeptides, linezolid), high drug concentrations, knowledge of resistance pattern of the microorganism, and long-term therapy are the cornerstones of treatment.

D. Intravascular Catheters

Because of the increasing incidence of vancomycin-resistant organisms, attempt to limit the indiscriminate use of vancomycin.

In patients with confirmed or suspected intravascular catheter infection associated with organ dysfunction, systemic emboli, or cardiovascular instability, the intravascular catheter should be removed promptly. In addition, local changes at the catheter site (purulence, erythema) mandate catheter removal. Coagulase-negative *Staphylococcus* and *S aureus* are the most common pathogens in catheter-related bloodstream infections. In the immunocompetent patient who has a coagulase-negative staphylococcal line infection but no systemic symptoms, the removal of the infected catheter line may be sufficient. Vancomycin is recommended in immunocompromised patients with coagulase-negative staphylococcal line infections, patients with systemic manifestations, or those with prosthetic devices at risk for becoming secondarily infected. If *S aureus* is the infecting organism, nafcillin is recommended; however, if there is a high rate of MRSA in the hospital or MRSA is confirmed, vancomycin should be used. Daptomycin can also be used; linezolid is less likely to be helpful but is sometimes used as part of a combination therapy or salvage therapy. A third- or fourth-generation cephalosporin or fluoroquinolone should be added if a nosocomial gram-negative organism is suspected.

Candida is occasionally isolated from catheter tips and should increase the suspicion that occult candidemia may have been recently present. The treatment of choice is fluconazole; if there is a possibility of resistant *Candida*, such as *Candida glabrata* or *Candida krusei*, an echinocandin (caspofungin/micafungin/anidulafungin) should be used. When a fungal microorganism is identified in an intravascular catheter-related bloodstream infection, a non-tunneled catheter always should be removed, whereas the removal of a tunneled catheter should be based on the likelihood of catheter-related candidemia rather than candidemia from another source. Antimicrobial-impregnated catheters appear to have a lower rate of bloodstream infection, but the maximum longevity of such catheters is still under investigation.

E. Abdomen

When an intra-abdominal infection is suspected, a surgeon must be involved in the evaluation of the patient. Definitive source control of intra-abdominal process may require surgical intervention or interventional radiology drainage. Both the infecting flora and the antimicrobial therapy are related to whether the infection was acquired in the community or healthcare setting. For community-acquired infections, location of a possible perforation determines the probable organism, with gram-positive, facultative, and aerobic gram-negative bacteria beyond the proximal small bowel and anaerobes beyond the proximal ileum. Recommended therapies include β-lactam/β-lactamase inhibitor combinations and carbapenems as monotherapy or cephalosporins/fluoroquinolones with metronidazole. Antimicrobial therapy should be continued until clinical resolution, which typically occurs in 5 to 7 days. Further diagnostic workup should be pursued in patients with persistent or recurrent symptoms. Flora isolated from healthcare-associated intra-abdominal infections resembles that of other nosocomial infections. Antimicrobial therapy should be based on knowledge of the flora and antimicrobial susceptibilities of the institution. Anti-enterococcal therapy is indicated only when enterococci are isolated from patients with healthcare-associated infections. Antifungal therapy is indicated only in those who have isolated fungi and comorbid conditions, such as recent immunosuppressive therapy for neoplasms, transplantation, and inflammatory disease, or who have postoperative or recurrent infections.

F. Urinary Tract

The most common pathogens in urinary tract infections are gram-negative enteric bacteria. Hospitalized patients with urinary catheters in place commonly have bacteriuria yet exhibit no pyuria or localized symptoms, classified as asymptomatic bacteriuria (ASB). Such patients (in the absence of urologic obstruction) rarely develop sepsis or bacteremia arising from the urinary tract, and removal of the catheter may allow resolution of the bacteriuria. For this reason, in patients with a short-term indwelling urethral catheter (less than 30 days), it is recommended to avoid screening or treating ASB. The Infectious Disease Society of America (IDSA) now only recommends screening for and treating ASB in pregnant women and those patients undergoing invasive urologic procedures. Patients who develop upper urinary tract infection always merit antimicrobial therapy. More serious complications may be seen in patients with diabetes mellitus or patients who are immunocompromised, including those with emphysematous pyelonephritis, papillary necrosis, or perinephric abscess, which may require surgical intervention. Empiric antimicrobial options for gram-negative urinary tract infections are dictated by susceptibility testing and include the following:

- Third-generation cephalosporins
- Aminoglycosides
- Piperacillin-tazobactam
- Trimethoprim-sulfamethoxazole

Enterococcal infection in the urinary system should be suspected in patients who have had urinary catheters in place for long periods or who have had recent manipulation of the urinary tract. Therapy should include ampicillin, piperacillin, or vancomycin. Narrowing of antibiotic therapy should be dictated by susceptibility testing.

Candiduria is not uncommon and usually occurs in patients who have long periods of urinary catheterization and are receiving broad-spectrum antimicrobial therapy or patients with glycosuria. For asymptomatic candiduria, therapy is not usually indicated unless the patient is at high risk (eg, neonates, unstable or neutropenic adults) or is undergoing urologic procedures. Therapeutic options include a short course of fluconazole (not effective against *C glabrata* or *C krusei*) or continuous amphotericin bladder irrigation; however, relapse rates are significant with either treatment. If candiduria is treated in a patient with an indwelling catheter, the catheter should be changed or removed during the treatment course.

G. Cutaneous Infection

S aureus or group A β-hemolytic streptococci are the most likely etiologic organisms in cellulitis or cutaneous abscess. *H influenzae* must also be considered in facial or orbital cellulitis. Onset of postoperative wound infections usually occurs 5 to 7 days after surgery. However, rapidly progressive wound infections occurring within 24 to 48 hours after surgery should prompt the consideration of *Clostridium perfringens* or group A β-hemolytic streptococci (*Streptococcus pyogenes*). This type of infection warrants surgical debridement and prompt antimicrobial therapy directed by Gram stain and culture results. Antimicrobial choices include the following:

- Cefazolin or nafcillin if methicillin-resistant *S aureus* is unlikely
- Vancomycin or linezolid if there is a possibility of methicillin-resistant *S aureus*
- Daptomycin because of its bactericidal properties
- Penicillin G with or without clindamycin for wound infections developing within 48 hours of surgery to cover *C perfringens* and β-hemolytic streptococci

Wound toxic shock syndrome is a rare condition that can occur within 48 hours of a wound or surgical incision. The causes are toxin-producing *S aureus* or β-hemolytic streptococci. Often, the wound does not appear infected because of a diminished inflammatory response. Diagnosis can be made based on presenting symptoms such as fever, diarrhea, vomiting, hypotension, and uremia. Erythroderma and subsequent desquamation are characteristic signs but may be delayed for several days. Treatment involves debridement, drainage, and prompt use of specific antimicrobial therapy.

H. Necrotizing Soft-Tissue Infection

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Antibiotics are adjuvant therapy to early and repeated debridement in necrotizing soft-tissue infection.

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Infection of the subcutaneous tissue, fascia, and muscle can occur in any patient but may be more common in immunocompromised patients, particularly individuals with diabetes mellitus. If gas is present in the tissue, cutaneous gangrene or bullae are noted, or infection progresses rapidly, a necrotizing soft-tissue infection must be considered. This condition requires prompt surgical debridement in addition to broad-spectrum antimicrobial therapy. These infections are usually polymicrobial, involving aerobic and anaerobic gram-positive and gram-negative organisms.

Adequate empiric therapy should include vancomycin and a β-lactam/β-lactamase inhibitor, a carbapenem and a fluoroquinolone, or an aminoglycoside and clindamycin (the latter to reduce the amount of toxins). Antimicrobial administration should be continued until no further debridement is needed and the patient's clinical status has improved. Prolonged courses of antibiotics can lead to wound colonization with drug-resistant organisms.

I. Immunocompromised or Neutropenic Patients

In the absence of a specific source, pending culture results, broad-spectrum antimicrobial therapy is indicated in the immunocompromised or neutropenic patient with fever. Initiation of monotherapy with an antipseudomonal beta-lactam agent, such as cefepime, a carbapenem, or piperacillin-tazobactam, is initially recommended. Additional agents such as aminoglycosides, fluoroquinolones, and/or vancomycin can be added to this regimen in patients with complicated presentations. Initial antibiotic therapy should be based on colonization or prior infection with a multidrug-resistant organism, site of infection, local antibiotic susceptibility patterns, presence of organ dysfunction, and previous antibiotic therapy.

The use of white cell growth factors (ie, granulocyte colony-stimulating factor, granulocytemacrophage colony-stimulating factor) may improve the outcome by shortening the duration of neutropenia. These progenitor cell stimulants should be targeted for patients with an anticipated duration of neutropenia of 5 to 7 days and a high risk for serious infection.

J. Clostridioides difficile (Cdiff) Infection

Antibiotic-associated diarrhea and colitis resulting from *Clostridioides (*formerly *Clostridium) difficile* infection can complicate the course of treatment for many patients. The antimicrobials most commonly involved include clindamycin, penicillins, cephalosporins, and fluoroquinolones, although *C difficile* has been described in association with almost all antimicrobials. Patients do not need to receive antimicrobial therapy to develop this condition.

C difficile is also recognized as an important nosocomial pathogen capable of cross transmission to patients in adjacent areas. Diagnosis is usually based on identification of *C difficile* toxins and detection of cytotoxic activity in tissue culture. Toxin testing is hampered by lack of sensitivity, and the polymerase chain reaction testing appears to be rapid, sensitive, and specific, and ultimately addresses testing errors. Repeat testing is not recommended within 7 days during the same episode of diarrhea. In those patients recently treated for *C difficile*, testing can remain positive even if symptoms have resolved.

Treatment begins with discontinuation of the implicated antimicrobial therapy (if possible) and initiation of specific antimicrobial therapy against *C difficile* if symptoms are moderate, severe, or persistent. The preferred regimen is oral vancomycin, 125 mg four times daily for 10 to 14 days or fidaxomicin for an initial episode. Metronidazole can be used for a non-severe initial episode if access to both vancomycin and fidaxomicin is limited or the patient is intolerant to these first-line options. For patients who are unable to take oral medications, intraluminal vancomycin with or without intravenous metronidazole is recommended. Fidaxomicin is a first-in-class, narrow-spectrum macrocyclic antibiotic that acts by eradicating *C difficile* with minimal disruption of the normal intestinal flora. High cost limits its use and in practice, fidaxomicin is used for recurrent *C difficile* infections or as a bridge to fecal microbiota transplant (FMT). A trial of treatment with either a vancomycin or fidaxomicin taper is recommended before pursuing FMT. Fidaxomicin is recommended along with oral vancomycin as a first-line option for treatment of an initial *C difficile* episode. Fulminant *C difficile* infection is present if the patient has any of the following: hypotension, ileus, or shock, and it is recommended to add IV metronidazole and increase the dose of vancomycin to 500 mg four times daily. Fulminant colitis unresponsive to these measures or progressing to toxic megacolon may require total colectomy.

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Proper infection control is important in the management of C difficile infections, including the use of soap and water for hand washing and not alcohol-based hand sanitizers.

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K. Fungal Diseases

Life-threatening infections caused by fungi may be extremely difficult to diagnose by routine physical examination or routine cultures. *Candida albicans* is the most common etiologic organism in critically ill patients. Non-albicans species of *Candida* and other fungi have increased significantly in recent years. Fungal infection should be considered in certain geographic regions and in the presence of predisposing factors, such as HIV, malignancy, neutropenia, long-term use of steroids, broad-spectrum antimicrobial therapy, parenteral nutrition, severe burns, organ transplantation, or central venous vascular catheters.

The polyenes (amphotericin B and lipid preparations of amphotericin B) have been the most commonly used antifungal agents for serious infections. Newer agents (echinocandins, voriconazole) have shown comparable or superior clinical outcomes compared with the polyenes and have much less toxicity than usually associated with amphotericin B. All lipid formulations have less nephrotoxicity, and their efficacy against *Candida* is equivalent to conventional amphotericin B. Fluconazole is still active against most *Candida* species and *Cryptococcus*, and itraconazole may be used for some of the mold infections. Both agents have an important role in primary or secondary prophylaxis. The newer agents, such as voriconazole, posaconazole, and echinocandins, have activity against resistant *Candida* strains and some of the mold infections resistant to other regimens. Voriconazole is the drug of choice for *Aspergillus* infection.

L. Other Therapy

In addition to antimicrobial therapy, surgical intervention must be considered in patients with life-threatening infections. Any abscess must be drained and injured or ischemic organs must be repaired or removed. Vascular catheters that may be a source of infection should be removed.

Early surgical consultation should be sought when the abdomen may be a source of infection in the critically ill patient. Guidelines for tetanus prophylaxis are found in **Chapter 12**. Further management of the patient with septic shock is discussed in **Chapter 8**.

M. Healthcare-Associated Infection Control

Patients can acquire healthcare-associated infections (HAIs) during the course of receiving treatment for other conditions within a healthcare setting. For example, pneumonia would meet the healthcare-associated criteria if the patient was hospitalized for at least 2 of the preceding 90 days, was a resident in a nursing home or extended-care facility, received home intravenous (antibiotics or chemotherapy) therapy, or received chronic dialysis or home wound care (or both) during the preceding 30 days.

Recent data estimate that one in every 25 hospitalized patients experience a HAI each year. Pneumonia and surgical site infection from any inpatient surgery were the most common HAIs. Many studies show that HAI increases hospital length of stay and morbidity and mortality rates. Strategies have been proposed to prevent HAI. Most important is proper hand hygiene and use of personal protective equipment (PPE). More details are available in the websites listed at the conclusion of this chapter. Guidelines cannot always account for variations among patients and are not intended to supplant physician judgment with respect to individual patients or special clinical situations.

Key Points

Life-Threatening Infections

- Fever is the most frequent systemic manifestation that raises the suspicion of infection.
- Ideally, appropriate cultures should be obtained before initiation of antibiotics in patients with suspected infection.
- Selection of appropriate empiric antimicrobial therapy depends on the suspected pathogen(s) and site of infection, Gram stain results of available specimens from the suspected site, assessment for antimicrobial resistance, and comorbid conditions.
- Rapid administration of appropriate antimicrobials has been shown to be a critical determinant of outcome in a variety of severe infections including meningitis, community-acquired pneumonia, and septic shock.
- When bacterial meningitis is suspected clinically, antimicrobial therapy should be instituted immediately, without waiting for the results of lumbar puncture.
- For suspected septic shock, available evidence suggests that administration of appropriate antimicrobials within an hour is recommended because it has been associated with improved survival.
- The most common organism resulting in community-acquired, life-threatening pneumonia is *Streptococcus pneumoniae*.
- Resistant gram-negative organisms and *Staphylococcus aureus* are frequent causes of pneumonia in hospitalized patients or in those who require mechanical ventilation.
- Bactericidal antimicrobial therapy, high concentrations of the antimicrobial agent, the resistance pattern of the microorganism,

and long-term therapy are the cornerstones of therapy for infective endocarditis.

- When source control is an option for infection management, it should be implemented early, particularly for septic shock.
- Suspicion of intra-abdominal infection requires the prompt involvement of a surgeon.
- Necrotizing soft-tissue infection requires prompt surgical debridement in addition to broad-spectrum antimicrobial therapy.
- In the absence of a specific source and pending culture results, broad-spectrum antimicrobial therapy is indicated in the immunocompromised or neutropenic patient with fever.
- Fungal infection should be considered in the presence of predisposing factors, such as malignancy, neutropenia, broad-spectrum antimicrobial therapy, parenteral nutrition, severe burns, or organ transplantation, or if central venous vascular catheters are in place.

Suggested Readings

1. Ferrer R, Martin-Lochese I, Phillips G, et al. Empiric antibiotic treatment reduces mortality in severe sepsis and septic shock for the first hour: results from a guideline based performance improvement program. *Crit Care Med*. 2014;42(8):1749-1755.
2. Funk D, Kethireddy S, Kumar A. Improving outcomes in sepsis and septic shock: Getting it right the first time. In: Rello J, Lipman J, Lisboa T, eds. *Sepsis Management: PIRO and MODS*. Springer-Verlag; 2010.
3. Kalil AC, Metersky ML, Klompas M, et al. Management of adults with hospital-acquired and ventilator-associated pneumonia: 2016 clinical practice guidelines by the Infectious Diseases Society of

America and the American Thoracic Society. *Clin Infect Dis*. 2016:63(5):e61-111.

4. Kumar A, Ellis P, Arabi Y, et al. Initiation of inappropriate antimicrobial therapy results in a 5-fold reduction of survival in human septic shock. *Chest*. 2009;136(5):1237-1248.
5. Kumar A, Roberts D, Wood KE, et al. Duration of hypotension before initiation of effective antimicrobial therapy is the critical determinant of survival in human septic shock. *Crit Care Med*. 2006;34(6):1589-1596.
6. Lim WS, van der Eerden MM, Laing R, et al. Defining community acquired pneumonia severity on presentation to hospital: an international derivation and validation study. *Thorax* 2003;58:377-382.
7. McDonald LC, Gerding DN, Johnson S, et al. Clinical practice guidelines for the Clostridium difficile infection in adults and children: 2017 update by the IDSA and SHEA. *Clin Infect Dis*. 2018;66(7):e1-e48.
8. Mermel LA, Allon M, Bouza E, et al. Clinical practice guidelines for the diagnosis and management of intravascular catheter-related infection: 2009 update by the Infectious Diseases Society of America. *Clin Infect Dis*. 2009;49(1):1-45.
9. Metlay JP, Waterer GW, Long AC, et al. Diagnosis and treatment of adults with community-acquired pneumonia: An official clinical practice guideline of the American Thoracic Society and Infectious Diseases Society of America. *Am J Respir Crit Care Med*. 2019;200(7):e45–e67.
10. Nicole LE, Gupta K, Bradlye SF, et al. Clinical practice guideline for the management of asymptomatic bacteriuria: 2019 update by the Infectious Diseases Society of America. *Clin Infect Dis*. 2019;68(10):e83-e110.

11. O'Grady NP, Barie PS, Bartlett JG, et al. Guidelines for evaluation of new fever in critically ill adult patients: 2008 update from the American College of Critical Care Medicine and the Infectious Diseases Society of America. *Crit Care Med*. 2008;36(4):1330-1349.

12. Pappas PG, Kaufman C, Andes D, et al. Clinical practice guidelines for the management of candidiasis: 2016 update by the Infectious Diseases Society of America. *Clin Infect Dis*. 2016;62(4):e1-e50.

13. Rhodes A, Evans LE, Alhazzani W, et al. Surviving Sepsis Campaign: International Guidelines for Management of Sepsis and Septic Shock: 2016. *Intensive Care Medicine*. 2017;43(3):304-377.

14. Seymour CW, Liu VX, Iwashyna TJ, et al. Assessment of clinical criteria for sepsis: For the Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis-3). *JAMA*. 2016;315(8):762-774.

15. Shankar-Hari M, Phillips GS, Levy ML, et al. Developing a new definition and assessing new clinical criteria for septic shock: For the Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis-3). *JAMA*. 2016;315(8):775-787.

16. Singer M, Deutschman CS, Seymour CW, et al. The Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis-3). *JAMA*. 2016;315(8):801-910.

17. Solomkin JS, Mazuski JE, Bradley J, et al. Diagnosis and management of intraabdominal infection in adults and children: guidelines by the Surgical Infection Society and the Infectious Diseases Society of America. *Clin Infect Dis*. 2010;50(2): 133-164.

18. Timsit JF, Bassetti M, Cremer O, et al. Rationalizing antimicrobial therapy in the ICU: a narrative review. *Intensive Care Med*.

2019;45(2):172-189.

19. Tunkel AR, Hartman BJ, Kaplan SL, et al. Practice guidelines for the management of bacterial meningitis. *Clin Infect Dis*. 2004;39(9):1267-1284.

20. Yokoe DS, Anderson DJ, Berenholtz SM, et al. A compendium of strategies to prevent healthcare-associated infections in acute care hospitals: 2014 update. *Infect Control Hosp Epidemiol*. 2014;35(5):455-459.

Suggested Websites

1. Society of Critical Care Medicine. http://sccm.org.
2. Surviving Sepsis Campaign. https://www.sccm.org/SurvivingSepsisCampaign/Guidelines/Adult-Patients
3. Centers for Disease Control. http://www.cdc.gov.
4. Infectious Diseases Society of America. http://www.idsociety.org.

Chapter 12

BASIC TRAUMA AND BURN SUPPORT

✓ Objectives

- Prioritize and initiate a timely assessment of the traumatized patient.
- Initiate treatment of life-threatening traumatic injury.
- Use radiography in identifying significant traumatic injury.
- Identify and respond to significant changes in the patient's status after traumatic injury.
- Initiate early burn management.
- Review indications for initiating surgical consultation and/or transferring the patient to a higher level of care.

Case Study

A 37-year-old man was working at a construction site when he fell approximately 20 feet off of scaffolding. He was wearing his hard hat, but it had come off during the fall. He is difficult to arouse and only groaning. He has an open wrist fracture and bruising on his back and left flank. His vital signs include a blood pressure of 86/68 mm Hg, heart rate of 100 beats/min, and a respiratory rate of 32 breaths/min.

The patient is lethargic and only moves his upper extremities. His skin is cool and clammy.

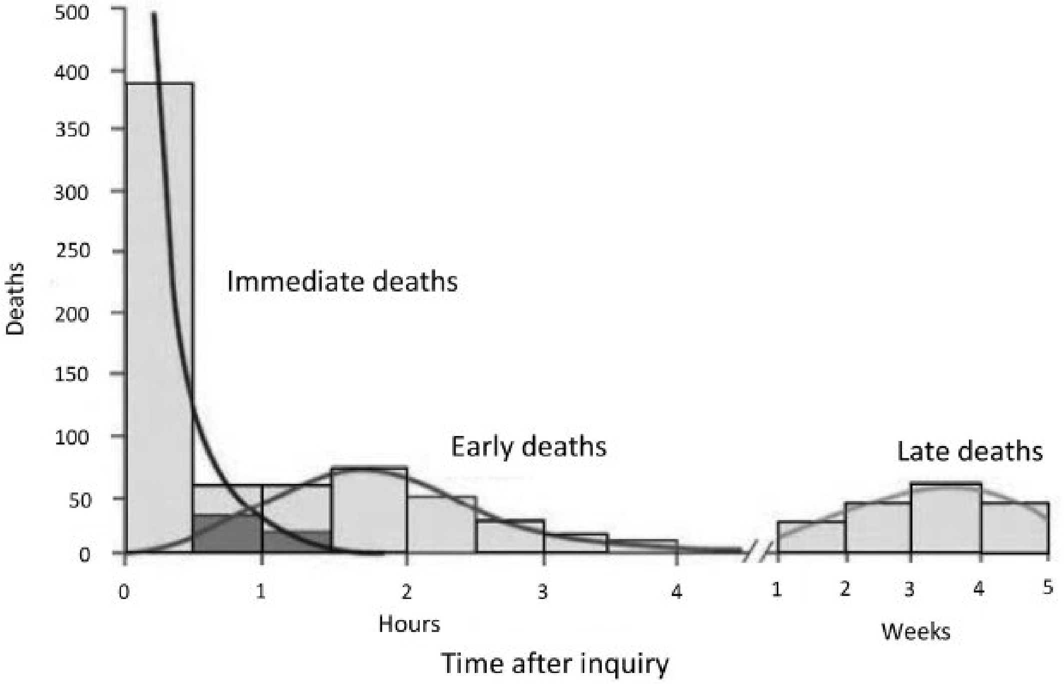
- What are the goals of the primary survey?
- What are the most urgent initial interventions?

I. INTRODUCTION

It is not the intention of the FCCS program to replace the Advanced Trauma Life Support (ATLS) course provided by the American College of Surgeons Committee on Trauma. Critical care is a component of caring for the injured person. The material presented here is intended to highlight evaluation and treatment issues for the provider confronted with a critically injured patient. Those providers who regularly encounter patients with traumatic injuries are encouraged to enroll in more formal trauma-specific training, such as the ATLS course.

In the United States, traumatic injuries remain the leading cause of death in individuals aged 1 to 44 years. Death as the result of injury occurs in one of three periods. The first period is within seconds to minutes of injury, when deaths generally result from severe brain or high spinal cord injury, loss of the airway, or rupture of the heart, aorta, or other large blood vessels. Few of these patients can be salvaged because of the severity of injury, and prevention is the only way to reduce such trauma-related deaths. The second period occurs within minutes to hours following injury; these deaths are usually the result of subdural and epidural hematomas, hemopneumothorax, solid organ rupture (spleen or liver), pelvic fractures, or other injuries associated with blood loss. The "golden hour" after trauma is characterized by the need for rapid assessment and resolution of these injuries. The third period occurs days to weeks after the initial injury and is most often caused by sepsis with associated multiple organ failure (**Figure 12-1**). Advances in critical care and multi-organ support have blunted the late peak that occurred at the 3–4 week interval, creating a bimodal distribution of mortality (immediate and early deaths). This is described in the work by Gunst et al (see Suggested Readings). This flattening of the curve emphasizes the importance of critical care in caring for the critically injured.

Figure 12-1. The Trimodal Distribution of Trauma Deaths



Reproduced with permission Feliciano D, Mattox K, Moore E. *Trauma*. 6th ed. New York: McGraw-Hill; 2008.

II. TRAUMA MANAGEMENT

The approach to the trauma patient follows a three-tiered approach:

1. Primary survey with simultaneous resuscitation – identify and treat life-threatening injuries
2. Secondary survey – head-to-toe evaluation and treatment, and patient history

3. Tertiary survey – all injuries are identified, catalogued, and treatment plans initiated

This three-tiered approach is guided by the following principles:

1. Treat the greatest threat to life first.
2. It is not necessary to establish a definitive diagnosis before initiating lifesaving treatment.
3. A detailed history is not essential to begin care.

Early management of the seriously injured patient requires simultaneous evaluation and treatment. The first goal is to ensure adequate oxygen delivery to vital organs by following an established sequence of priorities that allows identification and treatment of injuries causing immediate threats to life (primary assessment). Patient management should begin with the rapid primary evaluation and simultaneous resuscitation of vital functions, followed by a more detailed secondary assessment (head-to-toe examination), and finally, the initiation of definitive care. This process begins with the ABCDE of trauma care, which guides the identification of life-threatening conditions through the initial assessment sequence of airway, breathing, circulation, disability, and exposure (**Table 12-1**).

Table 12-1 Initial Assessment of Trauma

Airway: maintenance with restriction of cervical spine motion

Breathing: ventilation and oxygenation

Circulation: hemorrhage control

Disability: brief neurologic examination

Exposure/environment: clothing removed, avoiding hypothermia

A surgeon skilled in trauma management should be consulted early in the course for all serious trauma patients. Routing trauma patients to a center with trauma surgeons is crucial in the survival of these patients. When a surgeon is not immediately available or when the patient's injuries exceed the capabilities of the institution, the transfer process to a definitive care facility should be initiated without delay. While waiting for transfer to a definitive care facility, life-threatening injuries should be addressed and the patient's response to these interventions should be monitored and reassessed.

A. Primary Survey with Simultaneous Resuscitation

1. Airway

If the patient is able to communicate verbally, the airway is unlikely to be in immediate jeopardy. In this situation, a definitive airway is unlikely to be needed. A definitive airway is defined as a cuffed tube secured in the airway with the cuff inflated below the vocal cords. During evaluation of the airway, cervical spine motion should be restricted. Assessment of the airway includes inspection for foreign bodies and facial, mandibular, or tracheal/laryngeal fractures that may result in airway obstruction. Patients can develop signs of airway obstruction after a benign initial presentation; therefore, reassessment is paramount. Profuse bleeding from an oropharyngeal injury may warrant placement of a definitive airway.

> !
>
> *Airway patency should be reassessed frequently, particularly in patients with head injury, shock, facial fractures, facial burns, and potential inhalation injury.*
>
> !

The patient's neurologic status (disability) is related to the airway. Patients with a severe head injury, a Glasgow Coma Scale (GCS) score of 8 or less, usually require placement of a definitive airway. Nonpurposeful motor responses support the need for immediate airway management (**Table 9-5**). Reassessment of airway patency and neurologic status throughout the resuscitation is essential, and supplemental oxygen should be administered to all severely injured trauma patients.

After blunt trauma, airway control should proceed on the assumption that an unstable fracture or ligamentous injury of the cervical spine (C-spine) exists. If active airway intervention is needed before evaluation for possible C-spine fracture, the technique chosen for airway control (intubation, adjunctive device, or surgical airway) should take into account the expertise of available personnel, type of equipment available, patient factors, and injuries. If the patient is apneic or deteriorating rapidly, effective bag-mask ventilation can be lifesaving. Standard orotracheal intubation should be attempted with the use of cervical spine motion restriction. Proper cervical spine motion restriction may be accomplished from the front or the side of the patient. One care provider supports the occiput and mandible with both hands to maintain neck alignment without applying traction or distraction. With secure stabilization, the anterior portion of the cervical collar may be removed to allow airway interventions. Cervical spine motion restriction is continued until the cervical collar is replaced and the definitive airway device is secured.

If the patient is combative and needs an airway, a drug-assisted intubation should be performed.

If a definitive airway cannot otherwise be secured, adjunctive devices (eg, laryngeal mask airway, esophageal-tracheal double lumen airway) can be considered, but a surgical airway is indicated.

Other key issues in airway control deals with concomitant facial fractures. Facial fractures are not an immediate priority unless heavy bleeding or uncontrollable secretions are present. Similarly, facial fractures usually do not require that the patient be intubated. Mandibular fractures, however, are more likely to be associated with soft-tissue injury that may compromise the airway. Orotracheal intubation or surgical airway should be performed if a definitive airway is needed.

If unable to achieve orotracheal intubation or adequately oxygenate/ventilate a patient, an emergent cricothyroidotomy is indicated or tracheostomy, when tracheal/laryngeal injury is suspected.

2. Breathing

Whereas many injuries can eventually affect the ability to ventilate and oxygenate, several important injuries need to be identified and managed urgently. These include: tension pneumothorax, open pneumothorax, and massive hemothorax.

Tension pneumothorax – this is a clinical diagnosis resulting from air in the pleural space affecting the patient's physiology. Treatment (chest tube) should be performed prior to obtaining a chest radiograph. Patients who are breathing spontaneously have signs of tachypnea, air hunger, and absent breath sounds on the affected side. Although hemodynamic collapse can develop in any patient, it may be the presenting signs in patients receiving positive pressure ventilation. Other findings include tracheal deviation away from the side of injury and distended neck veins. See **Chapter 6** for more detailed information.

Open pneumothorax – is generally associated with chest wall soft-tissue loss creating a "sucking chest wound". Prehospital providers commonly treat this injury at the scene with air-occlusive dressing secured on three sides. Once at the hospital, a chest tube should be placed and definitive wound closure should be performed in the operating room. Prior to definitive wound closure, a sterile dressing should be applied to the wound.

Massive hemothorax – is suggested by the patient's physiology, physical examination, and chest radiograph. It is often defined as > 1,500 mL of blood (which corresponds to Class III hemorrhagic shock) in the pleural space, or ongoing blood loss of > 200 mL per hour for subsequent 2 to 4 hours. This amount of blood in the pleural space can compromise oxygenation and ventilation. A chest tube should be placed and surgical consultation obtained for possible thoracotomy. Auto-transfusion of the scavenged blood from the pleural space can aid in the patient's resuscitation.

Other injuries associated with breathing problems include a simple pneumothorax and rib fractures. Usually, a simple pneumothorax is associated with rib fractures and may require chest tube placement. These patients often present with chest wall tenderness. Subcutaneous emphysema may be palpable. A chest radiograph with subcutaneous air is highly suspicious for a pneumothorax and a chest tube should be placed. High consideration should be given to placement of a chest tube in any patient who has a pneumothorax on a chest radiograph and is receiving general anesthesia and positive pressure ventilation.

Rib fractures are often missed on a chest radiograph; however, a fracture may be suspected and documented when tenderness over the fracture is identified during physical examination. Pain control may be required to ensure adequate spontaneous ventilation. These patients can develop hypercapnic respiratory failure from inadequate ventilation; therefore, their ventilation and oxygenation should be continually monitored. Flail chest is defined as two or more fractures in two or more consecutive ribs. This may result in paradoxical chest movement (ie, inward movement of the flail segment during inhalation). Flail chest is also associated with contusion of the underlying lung, pain, and hypoxemia. These patients require aggressive pain control and continuous monitoring of oxygenation and ventilation. They may need to be intubated because of severe respiratory compromise.

Case Follow-up: A 37-year-old man was working at a construction site when he fell approximately 20 feet off of scaffolding. He sustained a high-grade splenic injury requiring splenectomy and a spinal cord contusion at T10.

3. Circulation

Case Study

A 22-year-old woman presents to the emergency department with a gunshot wound to the right thigh. Her initial blood pressure is 92/78 mm Hg and heart rate is 130 beats/min. She has received 1 L of crystalloid fluid by EMS with some improvement in blood pressure to 108/70 but returns to the previous blood pressure reading. She is confused and thrashing about.

- Is this patient in shock?
- What is the primary concern?
- What therapy is recommended?

> *If the initial fluid bolus produces only transient improvement or no response, immediate surgical consultation is required. Transfusion of blood products should be initiated as well.*

The leading cause of shock in a trauma patient is hemorrhage. The primary goal is to identify and stop the hemorrhage and restore tissue oxygenation as soon as possible. Initial empiric treatment in adults consists of warmed isotonic crystalloid infusion (1 L of lactated Ringer or normal saline solution) via two large-bore (minimum 18-gauge) peripheral intravenous catheters and control of external hemorrhage by means of manual compression. Targets for empiric fluid therapy are normalization of blood pressure, reversal of tachycardia, and maintenance of adequate organ perfusion (**Chapter 8**). Patients with no traumatic brain injury, but extensive hemorrhage that may require surgical intervention, are better managed by resuscitation with permissive hypotension to a systolic blood pressure of 90 to 100 mm Hg until surgical control of the hemorrhage can be accomplished. This action supports control of vessels that may have thrombosed and are not presently bleeding, but may rebleed if the blood pressure is normalized. When hypoperfusion and vascular compensation limit peripheral access, cannulation of a central vein (ideally with a 7F, 8.5F, or 9F introducer) is an alternative, as is intraosseous access. Concomitant diagnostic studies for the source of bleeding can include chest radiographs (hemothorax), pelvic radiograph (pelvic fracture, open-book or vertical pelvic shear injury), focused assessment sonography in trauma (FAST), or diagnostic peritoneal aspirate (DPA) or lavage (DPL) [intraperitoneal hemorrhage]. If the patient is hemodynamically stable, a computed tomography (CT) scan of the abdomen and pelvis ideally with intravenous contrast may be performed to better delineate the injuries and evaluate the retroperitoneum, unless a definitive indication to operate is present. A patient who is hemodynamically unstable should not be moved for CT scanning. Immediate control of external hemorrhage should proceed simultaneously with rapid resuscitation. When trauma is present in an extremity, direct pressure is recommended. This can be accompanied by a hemostatic gauze dressing. If bleeding persists, a tourniquet should be applied on the extremity above the injury. Blind clamping in a bleeding wound is discouraged to avoid potential injury to adjacent structures.

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It is critical not to equate the absence of hypotension with the absence of shock. Patients may have significant blood loss (Class I or II shock) without a change in blood pressure.

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As shown in **Table 12-2**, a patient's systolic blood pressure, heart rate, respiratory rate, and mental status can be used to assess blood loss. The American College of Surgeons also validates a decrease in pulse pressure as a sign of occult hypoperfusion. Circulating blood volume corresponds to 7% of normal body weight (70 mL/kg) in an adult. Blood loss up to 1,200 mL may occur in a normotensive adult (70 kg [154 lb]) with minimal tachycardia. Class II hemorrhage is uncomplicated shock, but crystalloid resuscitation may be sufficient. Class III hemorrhage requires crystalloid resuscitation and often blood replacement. Class IV hemorrhage can be considered preterminal and requires aggressive measures to restore intravascular volume, oxygen-carrying capacity, and to control bleeding. Treatment should be directed by the initial response to therapy rather than by a classification scheme. Patients will respond to fluid resuscitation in one of three ways. One group of patients, known as rapid responders, will regain normal vital signs with small volumes of fluid. A second group of patients, known as transient responders, will initially respond to the fluid resuscitation, but then demonstrate signs of hemodynamic deterioration with time or a decrease in the fluid resuscitation. These patients will require additional fluids and focused evaluation of the etiology and treatment of the injuries. This transient response is suggestive of ongoing hemorrhage. The third group of patients, known as non-responders, will not show signs of physiologic improvement despite volume resuscitation; these patients often need immediate surgical intervention. They likely have ongoing major hemorrhage. Without rapid and aggressive intervention, their mortality will be high and they may ultimately receive massive transfusions (> 10 units of packed red blood cells [PRBCs] in the first 24 hours of admission or more than 4 units in 1 hour).

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> *Ionized calcium may need to be followed and repleted ascitrate in PRBCs may chelate calcium, promoting a coagulation defect in patients receiving massive transfusions.*
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When beginning resuscitation for patients in shock, isotonic crystalloid can be used. However, the volume should be controlled and minimized to no more than 1 L. If there is an inadequate physiologic response, this therapy should be followed by the early administration of blood products. Fully crossmatched blood is rarely available for emergency trauma resuscitation. Uncrossmatched type-specific blood can be safely administered and is available in many hospitals within 15 to 20 minutes after a request is received. If type-specific blood is not available and the patient is unstable, O-negative PRBCs should be used. In most trauma centers, uncrossmatched blood is almost immediately available in the trauma resuscitation area for use in the unstable trauma patient. O-positive PRBCs are an option for men and women beyond childbearing age.

Table 12-2 Hemorrhage Classification Signs and Symptoms

Parameter	**Class I**	**Class II (Mild)**	**Class III (Moderate)**	**Class IV (Severe)**
Approximate blood loss	<15%	15-30%	31-40%	>40%
Heart rate	↔	↔/↑	↑	↑/↑↑
Blood pressure	↔	↔	↔/↓	↓
Pulse pressure	↔	↓	↓	↓
Respiratory rate	↔	↔	↔/↑	↑
Urine output	↔	↔	↓	↓↓
Glasgow Coma Scale score	↔	↔	↓	↓
Base deficit[a]	0 to -2 mEq/L	-2 to -6 mEq/L	-6 to -10 mEq/L	-10 mEq/L or less
Need for blood products	Monitor	Possible	Yes	Massive transfusion protocol

[a] Base excess is the quantity of base (HCO_3-, in mEq/L) that is above or below the normal range in the body. A negative number is called a base deficit and indicates metabolic acidosis.

Reproduced with permission Mutschler M, Nienaber U, Brockamp T, et al. A critical reappraisal of the ATLS classification of hypovolaemic shock: does it really reflect clinical reality? *Resuscitation*. 2013;84(3):309-313.

In situations in which massive transfusion is anticipated or probably likely, the early use of a balanced resuscitation using a combination of PRBCs, fresh frozen plasma, platelets, and cryoprecipitate should be strongly considered. In these situations, the most urgent priority is control of ongoing hemorrhage. Typically, this involves surgical intervention. However, with certain injuries, especially severe pelvic fractures with active bleeding into a pelvic hematoma, other interventions, such as angiography with embolization, can be lifesaving. Many trauma centers have a massive transfusion protocol in place to allow the rapid procurement of blood products for administration in the critically injured, unstable, massively bleeding patient. Developing evidence suggests that the administration of crystalloid solutions should be minimized, especially in this population. There is also increasing evidence that the use of ratio-based blood product resuscitation (PRBCs, fresh frozen plasma, and platelets close to a 1:1:1 ratio) improves outcomes and may decrease the physiologic insult to these critically ill patients. Ratio-based resuscitation likely provides some of the same benefits as the use of fresh whole blood and may be helpful in minimizing the coagulopathy that can develop in patients who have massive injuries. Whole blood is available in some facilities and part of the massive transfusion protocol for patients in hemorrhagic shock. Investigations into the benefits of whole blood are still ongoing.

> *Patients with massive blood loss require an early and aggressive balanced resuscitation with PRBCs, fresh frozen plasma, and platelets, along with aggressive hemorrhage control.*

Tranexamic acid (TXA) may also be considered as part of the resuscitation of these patients but some evidence has shown increased thrombotic complications. Thromboelastography (TEG) or rotational thromboelastometry (ROTEM) may also be used to guide more precise replacement of product deficiency during the resuscitation.

4. Disability (Neurologic Evaluation)

Rapid neurologic evaluation is performed as part of the primary survey and includes determination of level of consciousness/GCS, pupillary size and reactivity, lateralizing signs, and gross level of spinal cord injury, if present. The GCS score is a quick, simple method for determining the level of consciousness and is predictive of outcome (specifically the best motor response). A decrease in the level of consciousness may reflect decreased cerebral perfusion or may be the result of direct brain injury. Hypoglycemia, ethanol, narcotics, and other drugs may also be involved. An altered level of consciousness indicates the need for immediate reevaluation of oxygenation, ventilation, and tissue perfusion. Changes in consciousness should be assumed to be caused by intracerebral conditions until proven otherwise. To improve patient outcomes, every effort should be made to prevent secondary brain injury and to ensure adequate oxygenation, ventilation, and blood pressure. If the patient's condition permits, a thorough examination prior to sedation and intubation may be performed to determine the presence of any localizing intracranial or spinal cord injury. Establishment of a definitive airway to control the airway and/or breathing and ventilation should not be postponed for a detailed neurologic examination. Once a neurologic injury is diagnosed, or even suspected, a referral should be made to a definitive care facility prior to additional imaging.

5. Exposure and Environmental Control

Throughout the initial resuscitation period, efforts should be made to control and prevent hypothermia. Patients are often hypothermic after environmental exposure, and the body temperature may fall further after administration of room temperature resuscitation fluids and cold blood, removal of clothing for examination purposes, loss of normal temperature-regulating reflexes in shock, or the use of some medications.

Patients may lose heat through any of multiple mechanisms including radiation, conduction (direct transfer), convection (air current), and evaporation. It is imperative to remove wet clothing. For example, patients with wet clothing lose heat faster because the thermal conductivity of water is far greater than that of air. In addition, because hypothermia contributes to coagulation abnormalities, cardiovascular collapse, and poor outcome, it should be avoided and treated.

The most common treatment strategies can be characterized as passive external rewarming and active rewarming (external and internal). Passive external warming measures include warming the environment, removing wet clothing, and providing insulating materials (eg, blankets). Additional maneuvers, such as active external rewarming measures, include warming blankets, heating pads, radiant energy, and force heated air systems. Active internal methods include warmed intravenous fluid to approximately 39°C (102°F) via a high-flow fluid warmer and warmed (40–45°C [104°F–113°F]) humidified air via an endotracheal tube. More invasive interventions include internal cavity lavage or extracorporeal blood warming.

6. Monitoring

Parameters such as heart rate, blood pressure, pulse pressure, respiratory rate, acid-base status, body temperature, and urinary output are used to guide adequacy of resuscitation. Evaluation begins during the initial survey and should be repeated frequently. Pulse oximetry is a valuable adjunct for monitoring hemoglobin saturation with oxygen in injured patients, but it is not useful for evaluating the adequacy of ventilation. Blood pressure, as the sole marker of resuscitation, may be a poor measure of actual tissue perfusion. Additional metabolic markers, such as serum lactate, base deficit, and pH, will assist in the determination of the adequacy of resuscitation. Perfusion of extremities may be evaluated by examining capillary refill as well as the presence of the peripheral pulses.

A urinary catheter should be inserted as soon as is practical to monitor urine output as a gauge of renal perfusion, although it must be used with caution in male patients when urethral injury is suspected (eg, blood at the urethral meatus, scrotal hematoma, or abnormal prostate on rectal examination). In these patients, a retrograde urethrogram can be used to rapidly evaluate for urethral injury.

7. Hemorrhagic Shock

As resuscitation proceeds, it is crucial to identify potential causes of hypotension. A search for occult blood loss should be undertaken after any external hemorrhage is controlled. The most frequent sites for such blood loss are the chest, abdomen, pelvis/retroperitoneum, and the soft tissues adjacent to long bone fractures.

a. Hemothorax

A chest radiograph (ideally with the patient in an upright or reverse Trendelenburg position if hemodynamically stable) is a reliable screen for intrathoracic bleeding. Ultrasonography of the chest also may reliably detect a hemothorax or pericardial fluid.

A hemothorax should be drained promptly by chest tube placement, with a subsequent radiograph to verify the location of the chest tube, blood evacuation, and lung expansion. As noted earlier, rapid loss of 1,500 mL of blood on chest tube insertion or continued losses of > 200 mL/h for 2 to 4 hours may necessitate a thoracotomy. If available, autotransfusion devices should be attached to any chest tube drainage canister placed for massive hemothorax.

b. Intra-abdominal Hemorrhage

Abdominal examination is often misleading in the detection of acute bleeding, especially in patients with lower chest trauma, rib fractures, spinal cord injury, intoxication, or altered level of consciousness. Any patient who has sustained significant blunt torso injury from a direct blow or deceleration, or a penetrating torso injury must be considered to have an abdominal visceral or vascular injury. Focused ultrasound for trauma and DPA or DPL are the most expedient methods of identifying significant intraperitoneal hemorrhage, although the FAST examination has largely replaced the use of DPL in most institutions. When readily available and used by trained individuals, FAST has the sensitivity, specificity, and accuracy of DPL in detecting hemoperitoneum requiring immediate surgical evaluation to determine the need for a surgical intervention. In stable patients with a positive FAST result, abdominal and pelvis CT scan with intravenous contrast may be appropriate to identify the source of bleeding and determine the need for any further intervention (eg, angiography for blunt solid organ injury). Abdominal hemorrhage frequently comes from splenic or liver laceration, other visceral injury, or retroperitoneal hematoma. Patients who are in shock are not candidates for CT scanning and require surgery to control bleeding.

c. Pelvic Hemorrhage

Assessment of bony stability by means of physical examination and plain radiographs of the pelvis is crucial for early identification of major pelvic fractures. Patients with pelvic fractures (particularly high-grade anterior-posterior compression or vertical shear) are at high risk for major bleeding, which is usually venous. Initial management includes vigorous blood volume replacement and, possibly, circumferential compression and mechanical tamponade with some form of pelvic binder. External skeletal fixation may be helpful if the fracture anatomy is appropriate, and an orthopedic surgeon should be consulted early in the course of treatment. In patients with arterial bleeding associated with pelvic injury, CT scanning will reveal a blush of contrast. Pelvic angiography for embolization should be considered in the hypotensive patient because of an increased likelihood for arterial bleeding. Angiography may be required in approximately 10% of patients with pelvic fractures. Recently, angiography has become the treatment of choice for control of bleeding from pelvic fractures and hematomas, even in the unstable patient.

d. Fractures

Patients with fractures will likely have associated hemorrhage in the surrounding injured tissue. Estimates of blood loss from various fractures are: rib 125 mL, radius or ulna 250–500 mL, humerus 500–750 mL, tibia or fibula 500–1,000 mL, femur 1,000–2,000 mL, pelvis 1,000 mL to massive. Multi-injured patients can have severe blood loss from their musculoskeletal injuries. This needs to be recognized quickly and appropriate resuscitation initiated promptly. In patients with long bone fractures, repeated physical examination for soft-tissue swelling and development of compartment syndrome is imperative in the management of these patients.

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A pelvic binder may be a commercially available device or a bedsheet wrapped tightly around the pelvis. This maneuver should center the compressive forces at the level of the greater trochanters.

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e. External Hemorrhage

External hemorrhage can be very dramatic, as with a lacerated major artery or vein where direct pressure will decrease blood loss. Other cases, such as scalp lacerations, may go unrecognized as a possible source of significant blood loss. Rapid application of direct pressure (with or without hemostatic gauze), temporizing suture repair, or application of a tourniquet to a bleeding extremity may be lifesaving. If a commercially available tourniquet is not available, an alternative method employs a blood pressure cuff inflated to a pressure higher than the patient's systolic blood pressure. Tourniquet use should be followed by surgical consultation because the tourniquet places the extremity at risk for ischemic injury. The time the tourniquet is placed should be written on the tourniquet and communicated to the receiving facility if the patient is transferred. In some situations, including military conflict and intentional mass casualty events, the early control of hemorrhage along with the liberal use of tourniquets can be lifesaving and may take priority in the initial evaluation and management.

8. Nonhemorrhagic Shock

The differential diagnosis of nonhemorrhagic shock in the trauma patient includes obstructive shock (tension pneumothorax, cardiac tamponade), cardiogenic shock (blunt cardiac injury), and distributive shock (neurogenic shock with acute spinal cord injury). Head injury is a rare cause of hypotension, but when it occurs, it is usually a preterminal event.

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If tension pneumothorax is suspected in an intubated patient, disconnect the patient from the ventilator and vent the pleural space with a finger thoracostomy or needle decompression followed by a tube thoracostomy. Manually ventilating the patient may reveal increased resistance.

a. Tension Pneumothorax

Tension pneumothorax causes hemodynamic compromise and pulmonary dysfunction because of acute compression of the lung parenchyma and a shift of the mediastinum away from the hemithorax with the increased pressure. Do not wait for a chest radiograph to make this diagnosis. Breath sounds will be absent, chest rise will be asynchronous, and patients may develop respiratory distress, acute desaturation, bradycardia, and occasionally, distended neck veins. Classic venous distension may be absent in the setting of pneumothorax complicated by hypovolemia. All but gross changes in breath sounds may be difficult to detect in the resuscitation room. Tracheal shift is a late sign and may not be a presenting finding. In adults, needle chest decompression in the midclavicular second intercostal space or finger thoracostomy at the fifth intercostal space anterior axillary line is performed; this is a lifesaving intervention that is followed by placement of a chest tube.

b. Cardiac Tamponade

The classic signs of cardiac tamponade—hypotension, distant heart sounds, jugular venous distension, and pulsus paradoxus—may be obscured because of noise and hypovolemia (decreasing jugular distension). Ultrasound (FAST) is a sensitive test for fluid in the pericardial sac. A pericardial window should be performed for the patient with refractory shock, persistent central venous hypertension, and a high-risk penetrating wound (between the nipples, above the costal margin, below the clavicles). When surgical expertise is not available, a needle/catheter pericardiocentesis may be performed as a temporizing measure. Occasionally, major blunt chest trauma ruptures the cardiac surface. Most cases involve atrial tears and can be repaired if diagnosed early.

c. Blunt Cardiac Injury

The diagnosis of blunt cardiac injury should be suspected in a patient involved in a high-speed, frontal impact accident who has unexplained hypotension or arrhythmia or, less commonly, cardiogenic shock. Changes in the electrocardiograms (ECGs) are usually nonspecific and can include premature ventricular contractions, bundle branch block, atrial fibrillation, unexplained sinus tachycardia, and ST-segment changes. If blunt cardiac injury is a possibility, a screening ECG should be obtained in the emergency department. If the patient has new abnormalities, the patient should be admitted for continuous ECG monitoring. For patients with preexisting abnormalities, comparisons with previous ECGs should be made. Hemodynamically stable patients with no ECG abnormalities and negative cardiac troponin need no further cardiac evaluation or observation. Echocardiography is indicated in patients with unexplained hypotension or arrhythmias to evaluate cardiac function and structural heart injury. Treatment includes correction of acidosis, hypoxia, and electrolyte abnormalities; judicious administration of fluid; and pharmacologic treatment of life-threatening arrhythmias.

Inotropes may be indicated to support hemodynamic function. It is important to ensure that refractory hypotension is not caused by ongoing blood loss. Patients may present with acute myocardial infarction secondary to cardiac injury, or an acute myocardial infarction may have led to trauma (ie, fall, motor vehicle crash). At times, these patients may need emergent cardiology consultation for heart catheterization.

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The right ventricle is most frequently involved in blunt cardiac injury, and volume challenge is the initial therapy for hypotension in the absence of pulmonary edema.

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d. Neurogenic Shock

Neurogenic shock, a physiologic state of shock, occurs when a cervical or high thoracic spinal cord injury (above T6 level) causes sympathectomy. Loss of vasomotor tone causes vasodilation of visceral and peripheral blood vessels. It is characterized by hypotension, frequently associated with relative or absolute bradycardia. Flaccid paralysis, loss of extremity reflexes, and priapism may be some of the initial associated neurologic findings. This is usually followed by spasticity. This spectrum of neurologic findings comprises spinal shock. Treatment for hypotension includes volume resuscitation and vasopressors (phenylephrine or norepinephrine) if volume loading does not reverse the hypotension. Atropine or dopamine may be considered in the presence of bradycardia associated with hemodynamic instability.

B. Secondary Survey: Diagnosis and Treatment of Other Injuries

Most patients with acute injuries can be resuscitated to a hemodynamically stable state. The primary survey should immediately identify acute life-threatening injuries. The next goal is to complete a secondary assessment to identify and treat other injuries. This assessment is crucial to allow proper triage to the operating room, radiology suite, or ICU. Keep in mind that should the patient's condition change, return to the primary survey and repeat the process.

1. History

Essential components of a patient's history include details of the mechanism of injury, previous medical illness, past surgical history (eg, inquiring about surgical scars), current medications, allergies, and tetanus immunization.

2. Physical Examination

The patient should be examined from head to toe. The skull is carefully inspected to identify occult injuries. Signs of basilar skull fracture include hemotympanum, rhinorrhea, or otorrhea; Battle sign (ecchymosis of the skin over the mastoid); and raccoon eyes. Facial bones, mandible, and neck are palpated for tenderness and crepitus. The GCS score and limited neurologic examination from the initial assessment are used to evaluate for head trauma (**Chapter 9**). Extraocular eye movements are checked to exclude muscle or nerve entrapment. The nares are inspected for blood and septal hematoma. The neck is inspected for distended neck veins, the position of the trachea, or subcutaneous emphysema. Neck pain or tenderness over the cervical spine warrants additional radiographs (see later section), CT, or magnetic resonance imaging. The chest is auscultated and palpated for tenderness and crepitus. The patient is logrolled so that the thoracic and lumbar spine can be palpated for tenderness and other injuries can be detected. In penetrating trauma, exclude occult entrance or exit wounds in the axillary, cervical, or inguinal regions. This may require a second full log roll to the opposite side or quarter roll. The abdomen is likewise inspected, auscultated, and palpated. The pelvic bones are assessed for stability with lateral compression, anterior-posterior compression, and a gentle translational motion; lack of pain with these motions in an awake patient without competing pain issues is usually sufficient to rule out significant pelvic bone fractures. Repeated examinations for pelvic stability should be avoided and may cause further injury. The rectum is evaluated for tone and the presence or absence of blood and to ensure that the prostate gland is not displaced or difficult to palpate. The presence of perineal/scrotal hematoma and blood at the urethral meatus implies potential urogenital injury, which is a risk for urinary catheter insertion. The extremities are inspected, palpated, and evaluated for range of motion and neurovascular integrity.

3. Laboratory Studies

Minimal testing includes complete blood count, electrolyte measurements, blood glucose level, blood alcohol level, and toxicology screening. Viscoelastic assays (TEG or ROTEM), if available, can better depict trauma-induced coagulopathy and provide guidance of massive transfusion protocols. In any patient with evidence of hypovolemia, blood-group typing, and a coagulation profile should be performed. Arterial blood gas measurements should be analyzed in selected patients to confirm adequate ventilation and perfusion (presence of acidosis). An elevated serum amylase level may be an indicator of pancreatic or bowel injury in the patient with blunt abdominal trauma, although it tends to increase several hours after initial injury. Creatinine phosphokinase should be checked and followed if rhabdomyolysis or compartment syndrome is suspected. The hematocrit may not reflect the patient's acute volume status; ongoing resuscitation equilibration by transcapillary fluid shifts can take hours to be reflected as a decrease in hematocrit. In general, a fall of 3% in the hematocrit is equivalent to 1 unit of blood loss. Serum lactate level measurements and follow-up to monitor clearance can help management and prognosis.

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Reevaluate laboratory results after initial resuscitation. Absolute values may not be as important as trends.

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4. Radiologic Evaluation

a. General

In the evaluation of blunt multiple-system trauma, a supine chest radiograph and supine view of the pelvis are generally obtained as the primary survey is performed. This allows for interpretation of completed radiographs as the secondary survey begins. Plain radiographs of the pelvis are crucial for early identification of major fractures and may allow for early placement of a pelvic binder to help reduce ongoing blood loss

b. Head

CT scanning is essential for initial evaluation of a head-injured patient or in any patient with a decreased or altered level of consciousness. Special consideration should be given to patients sustaining a blunt mechanism and are on anticoagulation and/or antiplatelet medications, especially in the elderly population. Many centers will also obtain a CT scan of the cervical spine when the head scan is obtained.

c. Spine

The initial lateral C-spine radiograph has been largely abandoned for the diagnosis of cervical spine injury. Given the common issues in obtaining adequate cervical spine images, including inadequate visualization of the spine between C7 and T1 and poor definition of the occiput, most centers now obtain a CT evaluation of any areas that cannot be clinically cleared or have concerning results on physical examination. In the patient with increased risk of C-spine injury, cervical immobilization is crucial until these studies are reviewed and correlated with a reliable physical examination for evidence of tenderness. However, patients should be removed from a rigid spine board expeditiously because of the risk of skin pressure injury with extended immobilization. Magnetic resonance imaging is helpful for disc, spinal cord, and ligament injuries. If a C-spine fracture is found, radiographic screening of the entire spine is indicated because ∼10% of these patients will have a second, noncontiguous vertebral column fracture. CT scans of the chest and abdomen often can be reformatted to provide information on spine injury without the need for additional plain radiographs or additional radiation exposure.

Neurologic examination alone does not exclude a C-spine injury. The following considerations apply to patients at risk for C-spine injury:

- Patients who are alert, awake, and have no changes in neurologic status or neck pain may be considered to have a stable C-spine and need no radiologic studies. Beware of injuries that could distract the patient with C-spine injury.
- Early CT scans may facilitate evaluation of the C-spine in any head-injured or intubated patient. Adding CT evaluation of the C-spine to the initial CT scan of the head is an appropriate strategy after injury.

- The presence of paraplegia or quadriplegia is presumptive evidence of spinal instability.
- Patients with neurologic deficits potentially the result of a C-spine injury require spine surgery consultation.
- Exclusion of any bony injury does not eliminate the possibility of ligamentous disruption. Magnetic resonance imaging can facilitate clearance of ligamentous injury if the examination is not reliable.

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Persistent pneumothorax despite a functioning chest tube or persistent air loss through the chest tube system may indicate a tracheobronchial injury.

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d. Chest

Once the spine is cleared for fractures, an upright (or reverse Trendelenburg) chest radiograph is indicated to better define or identify pneumothorax, hemothorax, mediastinal widening or irregularity (concern for aortic transection), or fractures, as well as to confirm the position of various tubes. Chest radiographs are inadequate to rule out aortic injury. When a significant lateral impact or deceleration injury occurs, an aortic injury should be suspected in a patient with a chest radiograph demonstrating a widened mediastinum. CT angiography provides an excellent method to screen for aortic injury and define other thoracic injuries. Its use has largely replaced traditional angiography in the initial diagnosis of thoracic aortic injuries.

e. Abdomen

Plain abdominal radiographs in blunt trauma are not usually helpful. In the hemodynamically stable patient, a CT scan of the abdomen and pelvis and the FAST examination are the mainstays of abdominal evaluation in a trauma patient. FAST can be followed up with a CT scan of the abdomen if free peritoneal fluid is identified in the stable patient. DPL may still be used in certain circumstances, but has generally been replaced by CT imaging and the FAST examination.

A nasogastric tube serves to decompress the stomach and may reduce the risk of pulmonary aspiration; however, it should be placed orally in patients with midfacial fractures or possible basilar skull fractures. Blood in the gastric aspirate may be the only sign of an otherwise occult injury to the stomach or duodenum, and further investigation may be indicated

f. Genitourinary Tract

Hematuria should be evaluated with a CT scan or other contrast studies. It provides anatomic detail about abdominal and retroperitoneal structures and any direct injury to the kidney(s). If physical examination suggests that a urethral injury is present, a urethrogram should be obtained before urinary catheterization. A cystogram may be indicated if bladder injury is suspected. Intravenous pyelograms are not overly valuable during the initial assessment.

g. Skeletal Fractures

Films of the extremities (anterior posterior and lateral views) should be obtained on the basis of physical examination or patient complaint. Films should include the joint above and below the site of fracture. Evaluation of the head and central injuries take precedence. In stable patient with no signs of vascular compromise secondary to their skeletal injuries deferring extremity radiographs is advisable to avoid delay in proceeding to CT.

5. Other Issues

Systemic antibiotics should usually be withheld until a specific indication is determined, but they are employed in three situations: (1) patients undergoing intracranial pressure monitoring or chest tube placement frequently receive gram-positive coverage when the device is inserted; (2) patients with penetrating abdominal trauma may be given coverage for gram-negative aerobic and anaerobic organisms for the first 24 hours after injury; and (3) patients with low-grade open fractures are given gram-positive coverage for 24 hours while high-grade open fractures require broad-spectrum coverage for 48 hours as orthopedic evaluation is arranged.

> *Remember to consult specialty services early so that they can offer input into treatment decisions.*

Another important issue is the need for adequate tetanus prophylaxis in patients with open wounds. The patient's current vaccination status must be verified and updated if needed. In those patients who have an unclear immunization status or with especially contaminated tetanus-prone wounds, the use of tetanus immune globulin should be considered (**Table 12-3**).

Table 12-3 Guide to Tetanus Prophylaxis in Routine Wound Management[a]

History of Absorbed Tetanus Toxoid	Clean Minor Wounds (Not prone to tetanus[b])		All Other Wounds[b] (Tetanus-prone[c])	
	Tdap or Td[b]	TIG[d]	Tdap or Td[b]	TIG[d]
Unknown or <3 doses	Yes	No	Yes	Yes
≥3 doses[e]	No[f]	No	No[g]	No

Abbreviations: Tdap, tetanus toxoid, reduced diphtheria toxoid, acellular pertussis vaccine; Td, tetanus toxoid and reduced diphtheria toxoid — for adult use (dose = 0.5 mL); TIG, tetanus immune globulin — human (dose 250 IU).

[a] Patients who have completed a three-dose primary tetanus vaccination series and have received a tetanus toxoid-containing vaccine <5 years before the injury do not require a tetanus toxoid-containing vaccine for wound management.

[b] Children <7 years – Tdap is recommended; if pertussis vaccine is contraindicated, Td is given. Children 7-9 years or adults >65 years = Td is recommended. Children and adults 10-64 years = Tdap is preferred to Td if the patient has never received Tdap and has no contraindication to pertussis vaccine. For patients >7 years of age, if Tdap is not available or not indicated because of age, Td is preferred to tetanus toxoid.

[c] Such as (but not limited to) wounds contaminated with dirt, feces, soil, and saliva; puncture wounds; avulsions; and wounds resulting from missiles, crushing burns, and frostbite.

[d] Equine tetanus antitoxin should be used when TIG is not available.

[e] If only three doses of fluid toxoid have been received, a fourth dose = preferably an adsorbed toxoid – should be given. Although licensed, fluid tetanus toxoid is rarely used.

[f] Yes, if ≥ 10 years since the last tetanus toxoid-containing dose.

[g] Yes, if ≥5 years since the last tetanus toxoid-containing dose; more frequent boosters are not needed and can accentuate adverse effects.

Female patients of childbearing age should be questioned about the possibility of pregnancy or be checked with a β-human chorionic gonadotropin test before extensive radiographic evaluation is performed unless significant hemodynamic instability is present. The priority with the unstable pregnant patient always has to be maternal resuscitation and stabilization. Any female in her second or third trimester should be positioned with a wedge under her back to elevate the right side, avoiding compression of the vena cava. This is done only after examination of the spine and pelvis does not reveal any pain or tenderness, which may indicate a fracture. Remember that the optimal care of the mother yields optimal care for the fetus. Obstetrical consultation should be considered.

Case Follow-up: A 22-year-old woman presents to the emergency department with a gunshot wound to the right thigh. She sustained a femoral shaft fracture and superficial femoral artery laceration. She initially underwent external fixation of the femur fracture and femoral artery reconstruction using contralateral vein graft. Definitive fixation is performed with an intramedullary nail.

C. Tertiary Survey: Ongoing Evaluation

Case Study

An 18-year-old man is in the ICU after sustaining a gunshot wound to the left chest traversing the diaphragm, left lobe of the liver, and spleen. In the operating room he underwent a left diaphragmatic repair after confirmation of no active bleeding coming from the thoracic cavity, left hepatic lobe repair, and splenectomy. Urine output was initially adequate along with blood pressure; however, it has been steadily decreasing along with increasing bloody drainage from the nasogastric tube. A viscoelastic assay obtained prior to the decline revealed no abnormalities.

- What is the possible cause of the bleeding?
- What should be the most appropriate first step in resuscitation?

Go back to the primary and secondary survey when a patient has a negative change to provide a framework to help organize the critical thinking process.

After life- and limb-threatening injuries have been addressed and metabolic derangements have been corrected, periodic systematic assessment is performed to identify occult injuries not evident at presentation. In addition, healthcare personnel must be prepared to return to the resuscitation phases and/or when conditions change. In the immediate period of the patient's course, these changes must not be viewed as a failure or "something was done wrong." This type of thinking or judgment will invariably lead to delays and potential adverse outcomes.

The administration of atropine or dopamine, as well as mydriatic agents, may dilate the pupils and lead to a false diagnosis of a more severe head injury.

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1. Head Injury

Evaluation of the head-injured patient is an ongoing process requiring early neurosurgical consultation. Serial assessment of the GCS scores, pupil size and response, and the presence or absence of lateralizing neurologic signs is crucial. Any changes in examination results are noted and acted on as they are discovered. Typically any change in the neurologic examination for the worse warrants a repeat head CT.

Serial CT scans of the head may offer clinically useful information, but the key to patient management is detection of changes in the physical examination. Repeat scheduled head CT is not uncommon for patients on blood thinners, such as warfarin or direct-acting oral anticoagulants (DOACs). Continued resuscitation is imperative to avoid secondary brain injury, which typically occurs when a patient becomes hypoxic or hypotensive during acute care. These secondary insults increase the likelihood of a poor outcome (**Chapter 9**).

2. Pulmonary Injury

Trauma patients often have a full stomach at the time of injury and experience aspiration. Aspiration of the acidic gastric contents may cause a chemical pneumonitis initially and predispose patients to an infective pneumonia or acute respiratory distress syndrome later. Antibiotics are not indicated in initial management. Early antibiotics can also make the patient more susceptible to resistant organisms. Bronchoscopy may be needed for removal of large particulate matter.

Delayed onset of pneumothorax or hemothorax may follow chest trauma. In addition, pulmonary contusions and resulting acute respiratory distress syndrome may not become obvious until later (12 to 48 hours). Continued assessment includes physical examination, oximetry and/or arterial blood gas measurements, chest radiographs, and ventilatory mechanics.

3. Cardiac Injury

Continuous ECG monitoring and frequent measurements of blood pressure are mandatory in the emergency department and ICU. Continuous arterial blood pressure monitoring may be indicated (**Chapter 7**). Electrolyte disturbances may lead to cardiac contractile dysfunction or arrhythmias in the aggressively resuscitated trauma patient. Common electrolyte disturbances include hyperchloremia, hypokalemia and hyperkalemia, hypomagnesemia, and hypocalcemia.

4. Abdominal Injury

Substance abuse or neurologic injury may not allow for a reliable initial abdominal examination. Perforation of a hollow viscus in blunt trauma is sometimes difficult to diagnose. Free air under the diaphragm on an upright chest radiograph, over the liver on a left lateral decubitus radiograph, or on an abdominal CT necessitates the need for surgical exploration. CT scanning also provides information about the retroperitoneum. In the head-injured patient who is undergoing a head CT scan and has a nonsurgical neurologic injury, abdominal scanning should be considered because physical examination may be unreliable. However, caution must be used in the clinical interpretation of CT imaging for a hollow viscus injury; a negative scan does not absolutely rule out the possibility of an occult injury.

An underdiagnosed condition is abdominal compartment syndrome. This condition occurs when intra-abdominal pressure increases because of intraperitoneal or retroperitoneal hemorrhage, ascitic fluid accumulation, edema secondary to massive fluid resuscitation, or intraoperative surgical closure of the abdomen under tension. Increased intra-abdominal pressure decreases cardiac output and compresses the vascular bed and kidneys. The diaphragm is displaced upward by increased intra-abdominal pressure, which results in decreased thoracic volume and compliance. Decreased volume within the pleural cavity predisposes to atelectasis, and ventilated patients with intra-abdominal hypertension require increased airway pressure to deliver a fixed tidal volume. Vascular compression can decrease blood flow to the liver and kidneys with resultant dysfunction. Finally, intra-abdominal hypertension significantly increases intracranial pressure. Typically, abdominal hypertension is manifested with decreased urine output, increasing peak airway pressures, hypotension, and an expanding tense abdomen.

5. Musculoskeletal Injury

> *In compartment syndrome, urgent fasciotomy is required with loss of pulse being a very late finding.*

The neurologic and vascular evaluation of the extremities is an ongoing process. A swollen and tense extremity should be watched closely for the development of a compartment syndrome, particularly in patients with decreased responsiveness. In alert patients, serial physical examination is the best monitoring method. Classic signs include pain, pallor, pulselessness, paresthesia, and/or paralysis. The most helpful early signs are reports of pain out of proportion to physical findings and severe pain on passive stretch of the involved muscle groups. In the unconscious patient or when the examination is unreliable, compartment pressure may be monitored using a needle with a pressure transducer. Pressures > 30 mm Hg warrant consideration of fasciotomy.

Musculoskeletal examination should be repeated, either as patients recover from other injuries or as their mental status clears, to identify new pain or tenderness. Plain radiographs should then be obtained to identify occult fractures. Orthopedic injuries commonly identified in a delayed fashion include fractures of the scapula, thoracic and lumbar spine, pelvis, ankle, and wrist.

Crush syndrome should be considered when patients have been trapped, injury to large muscle mass is involved, prolonged compression has occurred with protracted immobilization, or vascular compromise is present (such as tourniquet use or compartment syndrome). Crush syndrome develops when damaged myocytes lyse, releasing myoglobin, potassium, phosphorus, and calcium. Manifestations of this syndrome include cardiac dysrhythmias, renal failure, metabolic acidosis, and hypovolemia. Preemptive hydration before reperfusion of crushed muscle mass usually is accomplished before arrival at the hospital. Revascularization of ischemic extremities, fasciotomy for compartment syndrome, or release of tourniquets can mimic this situation. Before reperfusion, normal saline should be administered (1- to 2-L bolus or 10–15 mL/kg/h). Careful monitoring for cardiac signs of hyperkalemia should be instituted. After reperfusion, aggressive hydration to maintain urine output above 3 to 4 mL/kg/h helps prevent heme pigment-associated renal injury. Adjuvants, such as bicarbonate and mannitol, have been used.

The use of extremity tourniquets has become more frequent in the field. The length of time the tourniquet was in place and whether it was effective should be noted. Attention should be directed to the extremity(s) if effective tourniquet time exceeded 90 to 120 minutes because of the increased risk for complications such as compartment syndrome, rhabdomyolysis, reperfusion injury, and nerve damage.

6. Other Considerations

Resuscitation is an ongoing process. Traditional end points, such as normalization of blood pressure, heart rate, and urine output, may not always reflect complete correction of the shock state. The attainment of normal vital signs can occur even in the setting of tissue hypoperfusion, resulting in a compensated state of shock. Lactate concentration and resolution of metabolic acidosis may provide more definitive end points for adequacy of resuscitation. Because the time to normalization of these parameters is predictive of survival, additional resuscitation in the form of volume replacement, blood product transfusion, or support with vasoactive agents may be indicated within the first 24 hours following injury despite normal or near-normal vital signs. Persistence of a metabolic acidosis or elevated lactate concentration may be an early indicator of complications, including ongoing hemorrhage or abdominal compartment syndrome.

Damage control surgery (abbreviated to control of bleeding and decontamination of hollow organ ruptures with spillage) may be needed in the first 24 to 48 hours, before definitive surgery is performed. Many trauma patients benefit from delayed definitive surgery, particularly the repair of fractures, during this period of ongoing stabilization. Decisions to proceed with surgery should be made after appropriate consultation with the primary surgical service, a critical care physician, and other consultants as indicated.

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>
> *Some patients will benefit by undergoing stabilizing procedures such as washout, debridement, and placement of external fixation for open fractures followed by delayed definitive repair.*
>
> !

In the immediate resuscitation period, periodic reassessments are important. Once a patient is stabilized, all intravenous access sites should be reassessed. Because full sterile precautions to prevent line-related infections may not be feasible during emergency vascular access, many lines will need to be replaced. If central venous access is no longer indicated, it should be discontinued.

Case Follow-up: An 18-year-old man is in the ICU after sustaining a gunshot wound to the left chest traversing the diaphragm, left lobe of the liver, and spleen. He underwent hemostatic resuscitation including packed red blood cells, fresh frozen plasma, and platelet transfusions. Urine output improved as did nasogastric drainage.

III. BURN INJURY: INITIAL EVALUATION AND STABILIZATION

Case Study

A 56-year-old woman is brought to the emergency department after sustaining injuries in a house fire with an explosion. The patient was found outside the house, awake, alert, and reporting abdominal pain. On examination, she has blistering of her cheeks, soot around her nares, and blistering over her bilateral forearms and chest. You are asked to see the patient in the emergency department to assist during her initial care.

– What are the initial evaluation priorities?

– What is the greatest risk to this patient?

A. General

Burn injuries represent a significant cause of morbidity and mortality. Near a half million cases of burn injury occur each year with approximately 40,000 requiring hospitalization. Deaths from burn injury occur with greatest frequency as a result of residential fires with smoke inhalation. Like other forms of injury, burns tend to be frequent in the young and the elderly. Scalds are the most common form of childhood injury, whereas electrical and chemical injuries affect adults in the workplace. In 1975, mortality was approximately 25% for severe burns; however, with improvements in burn care, mortality is now around 4%. Factors that affect burn mortality include size of cutaneous injury, patient age, and presence or absence of inhalation injury. Burn injuries should not distract providers from seeking other potential traumatic injuries. The initial evaluation and treatment of a serious burn injury follows the same pathway as trauma, including the primary and secondary surveys.

B. Airway/Breathing

The initial evaluation of the airway is directed, in part, by the history of the injury. Patients who are at the greatest risk of smoke inhalation injury typically have a history of being in a closed space with flame and smoke. With increased exposure time, the likelihood of injury increases. Smoke inhalation injury can be described by three mechanisms. These include particulate injury, toxic byproducts of combustion injury, and direct thermal injury. Particulates found in the soot and smoke of the fire are responsible for a reactive airway injury that may result in bronchospasm. Toxic exposure may have a direct cytotoxic effect on alveolar tissue or affect energy-generating pathways, or bind hemoglobin and reduce the availability of oxygen for intracellular use. Direct thermal injury can result in oral, nasal, and upper respiratory injury with airway swelling.

At room air, the half-life of carbon monoxide in association with hemoglobin is 3 to 4 hours; breathing 100% oxygen, the half-life is only 30 to 90 minutes.

Inhalation injury, the leading cause of death in burns, is generally diagnosed by a combination of clinical signs and symptoms confirmed by bronchoscopy. Clinical findings include facial burns, parched oral mucosa, nasal singeing, soot in the oral and nasal passages, and symptoms of reactive airway exacerbation. Bronchoscopic findings include mucosal edema, ulceration, sloughing, and mucus plugging. Chest radiographs are frequently normal at admission, and hypoxemia often is not appreciated. Additional diagnostic studies to consider are serial arterial blood gases, peak expiratory flow rates, pulse oximetry, end-tidal CO_2, serum lactate, and carboxyhemoglobin.

Three stages of inhalation injury have been identified:

1. Acute hypoxia with asphyxia typically occurs at the scene of the fire.
2. Upper airway and pulmonary edema may evolve during the first hours to days after injury.
3. Infectious complications that stem from exposure to heat and chemical irritants may appear later (eg, pneumonia).

Treatment of inhalation injury may include supplemental oxygenation and bronchodilators. If exposure to carbon monoxide is suspected, 100% oxygen should be provided. Early intubation is advocated, especially if the patient will be transferred, because pulmonary and laryngeal injury may quickly evolve even though the initial airway assessment is satisfactory. Humidification of inhaled gases helps in secretion control and reduces desiccation injury to the airway. In those patients with potential inhalation injuries sustained in enclosed spaces, consideration should be given to the potential for cyanide toxicity in which administration of methemoglobin generators (eg, amyl nitrate, cyanocobalamin) is indicated.

C. Circulation

Patients with larger burns (> 20% total body surface area [TBSA]) may develop burn shock. This is the result of a diffuse capillary leak syndrome resulting from the release of cytokines, interleukins, and vasoactive amines and causing third spacing of fluid. The combined loss of fluid from the burned surface area and the interstitial edema may result in the loss of circulating volume. Systemic hypotension may ensue. Resuscitation following the American Burn Association recommendations (discussed later) should be followed because it permits large volumes of fluid to be administered over an extended period. Large-bore peripheral intravenous catheters should be placed (through the burn, if necessary). The preferred resuscitation fluid is lactated Ringer solution. Intravascular resuscitation should not be delayed or withheld, especially in patients with inhalation injury, because this increases resuscitation fluid requirements.

D. Assessment of Injury

The approach to the initial assessment is the same as in trauma. An initial primary survey (ABCDE) is performed, followed by a head-to-toe examination. All nonadherent clothing must be removed to determine burn size, and the patient must be covered with blankets because heat is lost quickly. Depending on the history, the patient may have other injuries and should be assessed for trauma in accordance with the guidelines outlined.

1. Depth of Burns

There are classically three burn depths. However, some describe up to six degrees of burn injury depending on the involvement of underlying subcutaneous tissue, muscle, and bone. For this course we will use four burn depths:

1. Superficial (first-degree): erythematous, painful
2. Partial thickness (second-degree)
    a. Superficial: painful, pink, edematous, and blistered
    b. Deep: red or mottled red and white, pinprick perceived as pressure as opposed to pain, +/- blisters
3. Full thickness (third-degree): white, leathery, painless
4. Fourth-degree: all layers of skin, fat, muscle, and bone

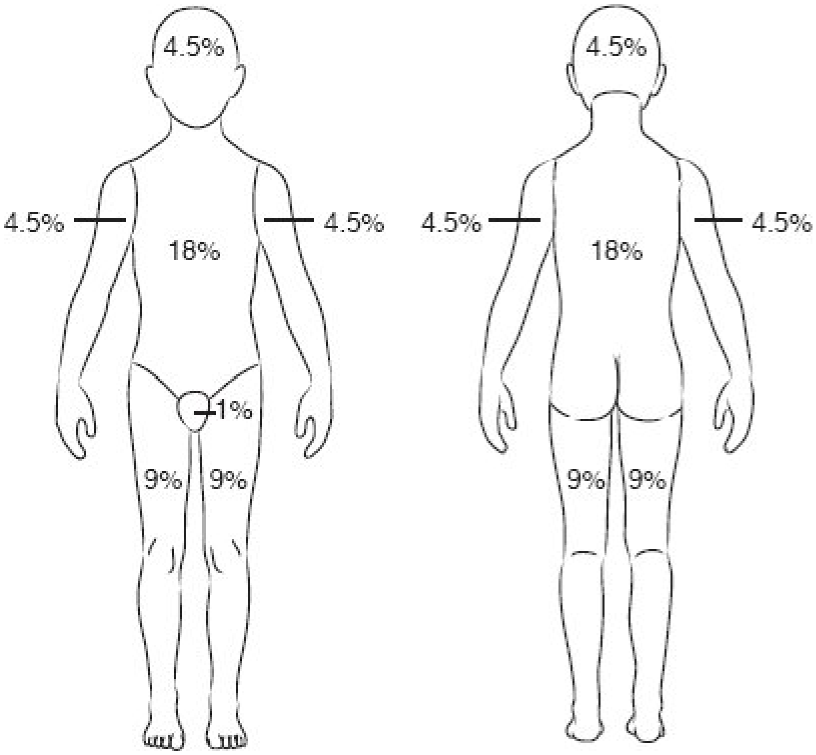
Full-thickness injuries and deeper usually require surgical intervention.

2. Burn Area (Rule of Nines)

The rule of nines is commonly used to estimate the surface area that has been burned (**Figure 12-2**). The head and upper extremities each represent 9% of the TBSA. The anterior and posterior trunk and the lower extremities each represent 18%, and the perineum represents 1% of the TBSA. In children, the head is proportionally larger, leading to a relative decrease in the area of other body segments. Alternatively, the patient's palm, which equals roughly 1% of TBSA, may be used to estimate the size of a small or irregular burn.

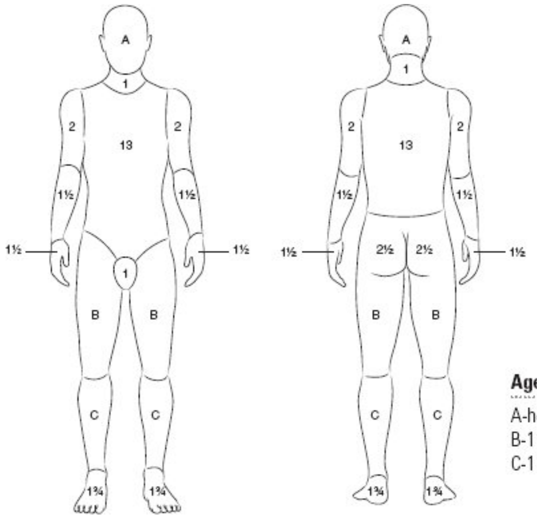
An often-used tool to estimate the TBSA in children younger than 15 years is the Lund-Browder Chart (**Figure 12-3**).

Figure 12-2. Rule of Nines


4.5%
4.5%
4.5%
18%
1%
9%
9%
4.5%
4.5%
4.5%
18%
9%
9%

Most appropriate for adults and children over 15 years of age.

Figure 12-3. Lund-Browder Chart



LUND-BROWDER CHART
Relative Percentage of Body Surface Area Affected by Growth

Age in years	0	1	5	10	15	Adult
A-head (back or front)	9½	8½	6½	5½	4½	3½
B-1 thigh (back or front)	2¾	3¼	4	4¼	4½	4¾
C-1 leg (back or front)	2½	2½	2¾	3	3¼	3½

The Lund-Browder chart is the most accurate method for estimating burn extent and must be used in the evaluation of pediatric patients under 15 years of age.

E. Resuscitation

Burn shock presents during the first 24 to 48 hours with profound hypovolemia, which has both interstitial and intracellular components. Increased capillary permeability is one of the key components of the burn shock response. In small burns, maximal edema is seen 8 to 12 hours after injury; larger burns at 12 to 24 hours. Plasma volume loss coincides with edema formation and increased extracellular fluid. Edema is affected by fluid administration during resuscitation. Fluid and electrolytes should be replaced as dictated by organ perfusion indicators and electrolyte imbalance. Because fluid and electrolyte losses in burns are primarily insensible, fluid lost cannot be quantified adequately. Venous access should be obtained and a urinary catheter placed. In the 2018 update to Advanced Burn Life Support, the American Burn Association recommends fluids in patients older than 14 years of age initiated at 500 mL/h with rapid titration to weight-based fluid infusion rates. For scald or flame burns, infants and young children weighing less than or equal to 30 kg should receive 3 mL lactated Ringer per kg per %TBSA and D5LR at maintenance rate. Children younger than 14 years of age should receive 3 mL per kg per % TBSA; adult and older children should receive 2 mL per kg per %TBSA. The rates are increased for electrical burns. All patients with electrical burns should receive 4 mL lactated Ringer per kg per %TBSA; however, infants and children should receive additional D5LR at maintenance rate.

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Although volume resuscitation formulas give a good estimate of the initial volume requirements for resuscitation in the critically burned patient, the most important indicator of appropriate resuscitation is adequate urine output.

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Beginning at the low end may reduce edema and extra-vascular complications such as abdominal compartment syndrome. The TBSA is calculated only for second- or third-degree burns. Resuscitation is carried out with lactated Ringer solution. Half of the crystalloid resuscitation should be administered in the first 8 hours after time of injury, the remaining over the next 16 hours. Confirming adequacy of resuscitation is more important than strict adherence to formulas. Surrogate markers of adequate resuscitation include normalization of blood pressure, heart rate, and urine output. Appropriate urine output in adults is 0.5 to 1 mL/kg/h and in children $>$ 30 kg up to age 17 is 0.5mL/kg/h and young children $<$ 30 kg is 1mL/kg/h. An arterial blood gas measurement to monitor the pH and base deficit and serum lactate levels are also good markers of adequate resuscitation. Although appropriate resuscitation is critical to maintain physiology, care must be taken to avoid over-resuscitation because this can lead to significant increases in peripheral edema, pulmonary edema, compartment syndromes, and result in increased morbidity of the burn injury. Once target urine output is reached, a gradual reduction of IV fluid administration is advised to prevent over-resuscitation.

F. Escharotomy

A circumferential burn to an extremity may develop significant edema that the underlying tissue cannot accommodate because of the constrictive nature of the burn wound. Impaired limb and tissue perfusion may ensue that can only be managed by performing an escharotomy to the extremity and/or digits. In larger burns of the abdomen and chest wall, a compartment syndrome may develop whereby cardiovascular and respiratory compromise may mandate torso escharotomies or abdominal decompression. Surgical consultation should be sought immediately for any of these problems.

G. Carbon Monoxide Exposure

A fire in an enclosed space mandates consideration of carbon monoxide poisoning in addition to the worry for inhalation injury. The typical oxygen saturation monitor will not detect carbon monoxide and can give artificially elevated oxygen saturation levels; therefore, if carbon monoxide poisoning is suspected, an arterial blood gas with a carboxyhemoglobin level will clarify the clinical picture. High-flow 100% oxygen will reduce the half-life of carbon monoxide in the plasma and is the primary treatment. Early use of hyperbaric oxygen for patients with high carboxyhemoglobin levels ($> 25\%$) or evidence of significant neurologic or cardiovascular toxicity has been recommended, but data supporting this recommendation are limited.

H. Burn Wound

Local wound care begins with serial debridement of nonviable tissue and blisters by appropriate surgical consultants. Little care, other than covering with a dry clean dressing to prevent hypothermia, is required for the burn wound before transfer to the burn center or surgical consultation. If gross contamination is present, a gentle washing and coverage with clean linen may be appropriate. If the patient cannot be transferred to a burn center within 24 hours, it may be necessary to cleanse the burns with a cleansing agent and apply appropriate topical antibiotic ointment (ie, silver sulfadiazine or bacitracin) and occlusive dressings to help prevent evaporative heat loss.

I. Other Considerations

Placement of a nasogastric tube and gastrointestinal stress ulcer prophylaxis are indicated if the patient vomits, requires intubation, or has a burn > 20% of TBSA. This may also prove beneficial to provide nutritional support for large burns, given the high nutritional requirements. Intravenous opiates should be given for pain. Rings and bracelets should be removed because they may cause constriction early in resuscitation. Burns are tetanus-prone injuries, and tetanus prophylaxis should be reviewed (**Table 12-3**).

J. Special Considerations

1. Chemical Burns

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Hydrofluoric (HF) acid burns can be particularly destructive, coagulating the skin on exposure as a result of fluoride ions penetrating the skin combining with cellular calcium and magnesium, requiring urgent wound excision. HF acid is commonly used in circuit boards, cleaning solvents, and paint removers.

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Chemical burns may be caused by acid (eg, cleaning products, industrial applications), alkali (eg, hydrides of sodium, potassium, and sodas of ammonia), or organic compounds (eg, petroleum products). Severity of injury relates to the agent involved, its concentration, and the duration of contact. Initial care requires removing the patient from the source of chemical injury immediately. In general, removal of clothing is essential. Dry substances should be brushed off and the area irrigated copiously with water. Do not use neutralizing agents because they may increase the severity of burn.

Contact with petroleum products (such as spilled gasoline at the scene of a motor vehicle crash) is associated with rapid skin penetration and late multiple-organ failure. Again, rapid removal of the patient from the source and vigorous irrigation of exposed surfaces are warranted. Advice regarding chemical burns is available from regional burn centers.

2. Electrical Injury

Electrical injury is a syndrome with a variety of presentations. Exposure to an electrical source of < 440 volts produces a low voltage injury similar to other cutaneous burns. When exposure exceeds 1,000 volts, a greater potential for deep as well as cutaneous injury exists.

Three types of skin injury can occur with electrocution:

1. Entrance and exit wounds, typically circumscribed, deep lesions, occur at points of contact with the electrical source or ground (usually hands and feet).
2. Cutaneous burns may be caused by arc injury from the primary site to the patient, a flash injury, or an actual flame injury if clothing catches fire.
3. Deep soft-tissue injuries involve muscle, nerve, or the vascular bed as current passes through the tissue.

Beware of pneumothorax, airway compromise, cardiac arrest, and blunt injury secondary to falls and violent muscle contraction. Muscle compartment pressures may increase, necessitating fasciotomy, not just escharotomy. If myoglobin is present in the urine or creatine kinase concentrations are elevated, provide adequate intravascular fluid to increase the urine output to 3 to 4 mL/kg/h until resolution of the rhabdomyolysis. Patients may develop ileus after electrocution. The ECG should be reviewed in electrical injury.

The initial priority in the management of electrocution is removal of necrotic tissue and decompression of compromised deep tissue compartments, particularly muscle. Resuscitation is begun at 4 mL/kg/% TBSA cutaneous injury and titrated to maintain a urine output of 0.5 to 1 mL/kg/h unless rhabdomyolysis is present and higher urine output is desirable. Aggressive fluid resuscitation potentiates filtering of pigment and dilution of iron (nephrotoxic). Alkalinization of the urine may be considered to decrease the nephrotoxic potential despite lack of supportive evidence. If large areas of soft-tissue injury are present, surgical consultation should be requested.

As with other burns, infection is the chief risk, but other potential problems are myocardial and vascular injury, encephalopathy, cataracts, and bowel perforation.

Lightning injury may be thought of as massive exposure to direct current. Most injury is topical because exposure times are extremely brief. Mortality rates associated with lightning relate to early cardiac and respiratory arrest. Aggressive basic and advanced life support may be lifesaving for these patients.

IV. REFERRAL AND TRANSFER CONSIDERATIONS

Early involvement of surgical expertise is important in the care of the injured patient. A surgeon should be summoned as soon as it is known that a seriously injured patient is arriving. Early neurosurgical consultation is advised for patients with head injury.

General guidelines for field triage and interfacility transfer have used physiologic, anatomic, and high-risk mechanistic criteria to suggest triggers for triage and transfer. One may extrapolate that these parameters can be used to initiate involvement of a trauma surgeon as well. The criteria for transfer of patients to burn centers according to the American Burn Association:

- Partial-thickness burns on greater than 10% TBSA
- Burns involving the face, hands, feet, genitalia, perineum, and major joints
- Third-degree burns in any age group
- Electrical burns, including lightning injury
- Chemical burns

- Inhalation injury
- Significant burns in patients at the extremes of age or with significant comorbid disease
- Patients with combined trauma and burn injury whose burn care supersedes the trauma care*
- Children at hospitals without qualified personnel or equipment to care for pediatric burn patients
- Burn injury in patients who will require special social, emotional, or rehabilitative intervention

*Patients with severe trauma with burns should be addressed at the nearest trauma center prior to consideration for transfer to burn center. For additional information on burn transfer criteria, see https://ameriburn.org/public-resources/burn-centerreferral-criteria/. Some additional triggers are suggested in **Table 12-4**.

If appropriate surgical services are unavailable, early transfer to the closest trauma or burn center should be initiated. This should not be delayed for additional radiologic studies if surgical resources are unavailable unless those studies are requested by the accepting physician. The trauma center should be contacted for advice and to discuss potential problems or concerns with transport personnel.

Common pitfalls in the transfer of seriously ill patients include failure to intubate before transfer, failure to recognize the need for transfer to a higher level of care, and a general failure to stabilize the patient adequately before transport. Unrecognized ongoing hemorrhage, delayed onset of tension pneumothorax, and reversible/preventable causes of secondary brain injury must be considered.

Case Follow-up: A 56-year-old woman is brought to the emergency department after sustaining injuries in a house fire with an explosion. She was intubated and placed on mechanical ventilation while her inhalation burns improved. She sustained a pneumothorax that required tube thoracostomy placement. The woman also underwent angioembolization of a splenic laceration with active extravasation of intravenous contrast.

Table 12-4 Indications for Field Triage and Interfacility Transfer[a]

Physiologic Criteria

- Glasgow Coma Scale score of <12
- Systolic blood pressure <90 mm Hg
- Respiratory rate <10 breaths/min or >29 breaths/min (<20 breaths/min in infant <1 year)

Anatomic/Injury Triggers

- Penetrating injuries to head, neck, torso, and extremities proximal elbow or knee
- Chest wall instability or deformity
- Amputation proximal to the wrist or ankle
- Two or more proximal long bone fractures
- Crushed, degloved, mangled, or pulseless extremity
- Pelvic fracture
- Open or depressed skull fracture
- Paralysis

Mechanism of Injury Triggers

- Adult: falls >20 feet
- Children: falls >10 feet
- High-risk automobile crash
  - Intrusion: >12 inches occupant side; >18 inches any side (including roof)
  - Ejections (partial or complete) from automobile
  - Death in same passenger compartment
  - Vehicle telemetry data consistent with high risk of injury
- Auto vs. pedestrian/bicyclist: thrown, run over, or with significant (>20 mph) impact
- Motorcycle crash >20 mph

Patient Triggers

- Age >55 years
- Systolic blood pressure <110 mm Hg in persons aged >65
- Falls in older adults (including ground level falls)
- Pediatric trauma transport
- Anticoagulant use or bleeding disorders
- Burns
- Pregnancy >20 weeks
- Judgment of emergency medical services provider

Adapted from Centers for Disease and Prevention. Guidelines for field triage of injured patients: Recommendations of the National Expert Panel on Field Triage, 2011. *MMWR Recomm Rep*. 2012;61(1):1-21.

Key Points

Basic Trauma and Burn Support

- The first goal in trauma management is to identify and treat immediately life-threatening injuries by following the ABCDE sequence of priorities.
- After blunt trauma, airway control should proceed on the assumption that an unstable cervical spine injury exists.
- A diagnosis of tension pneumothorax should be based on clinical criteria and not on a chest radiograph.
- Hemorrhage is the most likely cause of shock after injury, and initial empiric treatment consists of crystalloid infusion to normalize blood pressure, reverse tachycardia, and maintain adequate organ perfusion.
- In general, blood should be added to resuscitation early if the response is inadequate or if continued ongoing hemorrhage is suspected. Uncrossmatched, type-specific blood can be administered safely.
- A secondary assessment includes a head-to-toe examination to identify and treat potentially life-threatening injuries.
- Computed tomographic scanning is essential for the initial evaluation of head-injured patients with a depressed level of consciousness.
- Burn resuscitation is proportional to the area sustaining second- and third-degree burns and is titrated to signs of perfusion. Adequate urine output is one of the key indicators of adequate resuscitation.
- Closed-space smoke inhalation injury places the patient at high risk for upper airway and inhalation injury that may not be obvious at

the initial presentation.

- Surgical expertise should be secured early and transfer considered for those patients who require a higher level of care.
- Transfer to a specialized care setting should not be delayed for additional radiologic studies unless the accepting physician requests the studies.

Suggested Readings

1. American Burn Association. Advanced Burn Life Support Course Provider Manual. 2018 Update. Chicago, IL: American Burn Association; 2018.
2. American College of Surgeons Committee on Trauma. *Advanced Trauma Life Support for Doctors (ATLS): Student Course Manual*. 10th ed. Chicago, IL: American College of Surgeons; 2018.
3. American College of Surgeons Committee on Trauma. Guidelines for the operation of burn centers. In: *Resources for Optimal Care of the Injured Patient*. Chicago, IL: American College of Surgeons; 2014:100-104.
4. American College of Surgeons. Hartford Consensus Compendium. *Bulletin of the American College of Surgeons*. 2015;100(1S):1-88.
5. Bagley LJ. Imaging of spinal trauma. *Radiol Clin North Am*. 2006;44(1):1-12.
6. Brain Trauma Foundation. Management and prognosis of severe traumatic brain injury. *J Neurotrauma*. 2007;24(Suppl 1):i-S106.

7. Chan O, Wilson A, Walsh M. Major trauma. *BMJ*. 2005;330(7500):1136-1138.
8. Cheatham ML, Malbrain ML, Kirkpatrick A, et al. Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome, II: Recommendations. *Intensive Care Med*. 2007;33(6):951-962.
9. Elliott DC. An evaluation of the end points of resuscitation. *J Am Coll Surg*. 1998;187(5):536-547.
10. Gunst M, Ghaemmaghami V, Gruszecki A, et al. Changing epidemiology of trauma deaths leads to a bimodal distribution. *Proc (Bayl Univ Med Cent)*. 2010;23(4):349-354.
11. Gonzalez E, Moore EE, Moore HB. Management of Trauma-Induced Coagulopathy with Thrombelastography. *Crit Care Clin*. 2017;33(1):119–134. doi:10.1016/j.ccc.2016.09.002
12. Herndon DN, ed. *Total Burn Care*. 3rd ed. Philadelphia, PA: Saunders-Elsevier Inc; 2007.
13. Holcomb JB, Jenkins D, Rhee P, et al. Damage control resuscitation: Directly addressing the early coagulopathy of trauma. *J Trauma*. 2007;62(2):307-310.
14. Johnson JW, Gracias VH, Schwab CW, et al. Evolution in damage control for exsanguinating penetrating abdominal injury. *J Trauma*. 2001;51(2):261-271.
15. Latenser BA. Critical care of the burn patient: the first 48 hours. *Crit Care Med*. 2009;37:2819-2826.
16. Mattox KL, Moore EE, Feliciano DV, eds. *Trauma*. 7th ed. New York, NY: McGraw-Hill; 2012.
17. Morrison CA, Carrick MM, Norman MA, et al. Hypotensive resuscitation strategy reduces transfusion requirements and severe postoperative coagulopathy in trauma patients with hemorrhagic

shock: Preliminary results of a randomized controlled trial. *J Trauma*. 2011;70(3):652-663.

18. Pryor JP, Braslow B, Reilly PM, et al. The evolving role of interventional radiology in trauma care. *J Trauma*. 2005;59(1):102-104.
19. Rhee P, Nunley MK, Demetriades D, et al. Tetanus and trauma: A review and recommendations. *J Trauma*. 2005;58(5):1082-1088.
20. Rossaint R, Bouillon B, Cerny V, et al. Management of bleeding following major trauma: An updated European guideline. *Crit Care*. 2010;14(2):R52.
21. Sarrafzadeh AS, Peltonen EE, Kaisers U, et al. Secondary insults in severe head injury: Do multiply injured patients do worse? *Crit Care Med*. 2001;29(6):1116-1123.
22. Sasser SM, Hunt RC, Faul M, et al; Centers for Disease Control and Prevention. Guidelines for field triage of injured patients: Recommendations of the National Expert Panel on Field Triage, 2011. *MMWR Recomm Rep*. 2012;61(1):1-21.
23. Society of Critical Care Medicine. *Fundamental Disaster Management*. 3rd ed. Mount Prospect, IL: Society of Critical Care Medicine; 2009.
24. Stengel D, Bauwens K, Sehouli J, et al. Emergency ultrasound-based algorithms for diagnosing blunt abdominal trauma. *Cochrane Database of Syst Rev*. 2005;(2):CD004446. doi: 10.1002/14651858.CD004446.pub2.

Suggested Websites

1. Society of Critical Care Medicine. www.sccm.org
2. American Burn Association. www.ameriburn.org

3. Burn Surgery. www.burnsurgery.org.
4. Brain Trauma Foundation. www.braintrauma.org
5. American Association for the Surgery of Trauma. www.aast.org
6. Eastern Association for the Surgery of Trauma. www.east.org
7. World Society of the Abdominal Compartment Syndrome. www.wsacs.org
8. American College of Surgeons. www.facs.org/quality-programs/trauma/atls

Chapter 13

ABDOMINAL SURGICAL EMERGENCIES: PART 1

✓ Objectives

- Recognize the various patient presentations of abdominal emergencies and determine whether surgical consultation is necessary.
- Identify the signs and symptoms of toxic megacolon and discuss the importance of a multidisciplinary approach to toxic megacolon including early consultation of surgical and other specialty services.
- Compare and contrast etiologies and differing management approaches for small bowel obstructions (SBO).
- Define primary, secondary, and tertiary peritonitis.
- Recognize symptoms and grades of acute cholecystitis and discuss clinical guidelines to select appropriate treatment.
- Explain the etiology, presentation, diagnosis, and management of esophageal perforation.

I. INTRODUCTION

This chapter will review the pathophysiology and management of five common abdominal surgical emergencies which include toxic megacolon, small bowel obstruction, peritonitis, biliary emergencies, and esophageal perforation.

II. TOXIC MEGACOLON

Case Study

A 69-year-old man with a medical history including atrial fibrillation and congestive heart failure was involved in a motorcycle crash and sustained an open left femur fracture. He underwent open reduction and internal fixation (ORIF) of his femur fracture 3 days ago and received cephalosporin and gentamicin preoperatively. This morning his WBC is 17,000/mm^3, his abdomen is tender without peritonitis, and he had multiple loose bowel movements overnight.

- Which differential diagnoses need to be considered?
- Which diagnostic tests could provide helpful information?
- Which findings are important in deciding on medical versus surgical management?

A. Background and Pathophysiology

Toxic megacolon (TM) describes severe total or segmental colonic distension associated with systemic toxicity and signs of sepsis. An increasing incidence and severity of *Clostridioides difficile* infection in hospitals in the United States has contributed to a rise in the incidence of TM, which was classically associated with inflammatory bowel disease (IBD). Less common causes of TM include colitides due to other infections including *Salmonella*, *Campylobacter*, enterohemorrhagic *Escherichia coli (E. coli)*, and cytomegalovirus (CMV), ischemia, or mechanical obstruction from volvulus or cancer.

A basic understanding of large bowel anatomy is helpful when interpreting imaging studies. The colon can be divided into the cecum; ascending, transverse, descending, and sigmoid colon; and rectum. The cecum has the largest diameter at baseline and is therefore particularly at risk for distension, ischemia, and perforation. Cecal diameter of more than 10 cm is concerning for the development of ischemia and perforation, and one of the indications to consider for surgical intervention or at least immediate decompression. The transverse colon has the smallest diameter at baseline, and dilation beyond 6 cm is considered "megacolon." Duration, etiology of colonic dilation, and clinical examination are more important than absolute diameter with regard to prognosis and need for interventions.

From inside to outside, the colonic wall consists of mucosa, submucosa, muscularis, and serosa. Many processes eventually resulting in TM start in the mucosal layer and therefore patients may not have abdominal pain until further advancement of this process (**Figure 13-1**). Similarly, a severely diseased colon can appear "normal" on the outside during surgical inspection and might result in false reassurance that the colon is not the etiology of clinical deterioration.

Figure 13-1. Severe Pancolonic Distension

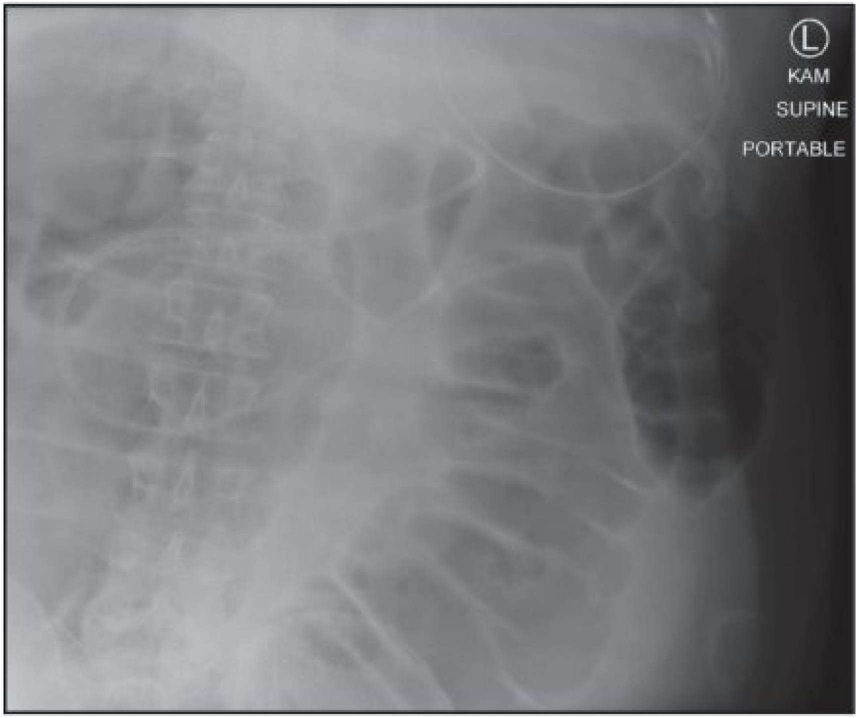

Image courtesy of S. Leichtle, MD, FACS

In TM from inflammatory, infectious, or ischemic etiology, an initially mucosal abnormality becomes a transmural process which ultimately leads to full-thickness pathology, peritonitis, and possible perforation. Colonic distension associated with these processes, or due to mechanical distal obstruction, causes stretching of the colonic wall, excessive tension, and local ischemia which progresses to transmural necrosis and perforation.

B. Clinical Presentation and Laboratory Findings

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> *Severe lactic acidosis should raise concern for the presence of ischemic or necrotic bowel, which is a surgical emergency.*
>
> ❗

Acute illness and systemic toxicity are part of the definition of TM and patients will have leukocytosis (or worse, leukopenia), tachycardia, and likely hypotension. Other inflammatory markers, such as lactate levels and C-reactive protein (CRP), are elevated. Severe lactic acidosis should raise concern for the presence of ischemic or necrotic bowel, which is a surgical emergency. In addition, patients may present with bloody diarrhea, but the absence of loose bowel movements should not lead the clinician to abandon a possible diagnosis of TM because ileus and obstipation are also a possible presentation. Examination of the patient's abdomen often demonstrates distension and tenderness, although true peritonitis is often absent unless perforation has occurred. Patients who are immunosuppressed either due to underlying comorbidities or due to their acute critical illness may have less obvious symptoms or laboratory abnormalities.

As demonstrated in the description of the patient at the beginning of the chapter, patient presentation and underlying etiology may vary substantially. TM due to *Clostridioides difficle (C. difficle)* infection usually follows worsening diarrhea in the setting of current or recent antibiotic use. Those patients with IBD often have a history of several days to a few weeks of worsening symptoms such as bloody diarrhea and malaise leading up to the acute presentation. Fulminant colitis marked by numerous, bloody bowel movements can also be the initial presentation of patients with newly diagnosed IBD. In patients with TM due to CMV, a diagnosis of immunosuppression due to human immunodeficiency virus (HIV) or transplant is usually present, and in cases of TM due to other bacterial infections, a history of recent exposure to risk factors may be elicited.

Acute mechanical obstruction from cancer or volvulus as a cause of TM always needs to be ruled out. Obtaining a history of risk factors or associated symptoms is important. However, TM also needs to be considered in the intubated, critically ill patient for whom only a limited history and examination are available.

C. Diagnosis

If circumstances, history, and/or physical examination raise concern for TM, the actual diagnosis is often confirmed on imaging studies. A supine abdominal radiograph will demonstrate a severely distended colon (**Figure 13-1**) or signs of mechanical obstruction such as the classic "coffee-bean" sign of sigmoid volvulus or apple core lesion of colorectal cancer. An upright chest radiograph or lateral decubitus abdominal radiograph will demonstrate free air in the setting of perforation, which would indicate a very severe presentation or late diagnosis of TM. In patients in whom the diagnosis is in question, a computed tomography (CT) scan of the abdomen and pelvis should be performed. A CT scan allows for more accurate determination of colon diameter (**Figure 13-2**), visualization of signs of bowel ischemia (pneumatosis or wall thickening), and can rule out the presence of distal obstruction. To achieve these goals, the CT scan should be performed with IV contrast and careful (risk of perforation) administration of rectal contrast.

In patients who cannot undergo CT imaging or in whom the diagnosis still is unclear, further clarification can be done with bedside sigmoidoscopy. This bedside procedure can be performed in the intensive care unit in patients who are too unstable to travel to the CT scanner. Sigmoidoscopy can demonstrate signs of *C. difficile* infection (pseudomembranes), mucosal necrosis (ischemic colitis), or ulcerations (IBD). Bedside sigmoidoscopy needs to be performed with extreme care with little to no insufflation to decrease the risk of iatrogenic perforation, which nevertheless exists. Full colonoscopy should not be performed due to the excessive risk of perforation.

Figure 13-2. Distention of Transverse Colon

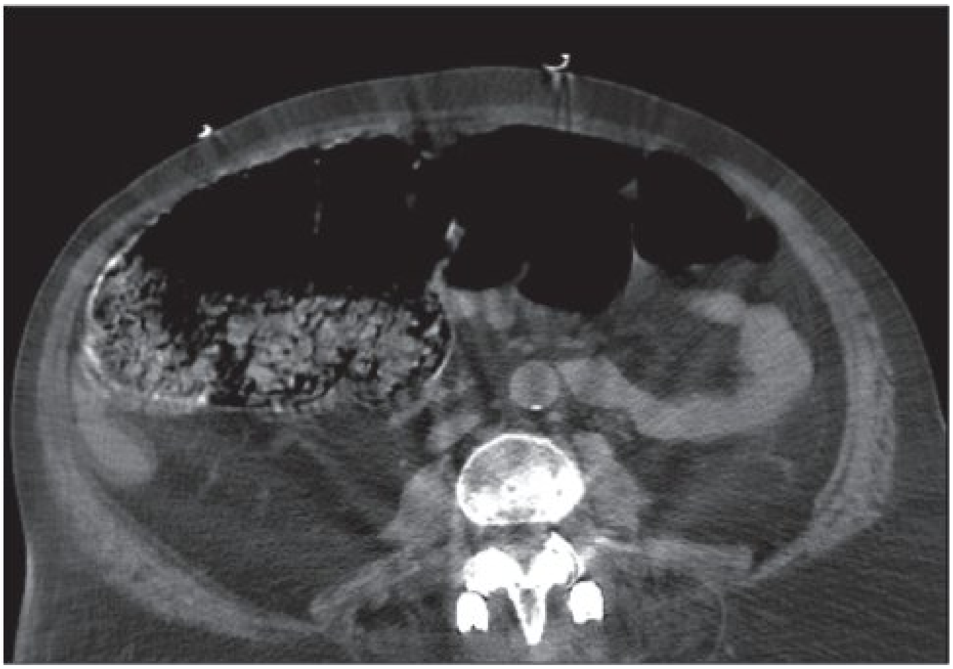

Image courtesy of S. Leichtle, MD, FACS

D. General Management

When the initial workup raises concern for colonic distension and megacolon, the following steps should rapidly be instituted (not all might be applicable to an individual patient).

- Strict nil per os (NPO) and decompression with a nasogastric tube. The latter does not decompress the colon, but it is helpful if ileus is present because this is common in critical illness.
- Surgical consultation to assess for surgical intervention and help with interventions such as decompression via rectal tube or bedside procedures such as sigmoidoscopy.

- Any electrolyte abnormalities (common are abnormal potassium, magnesium, and phosphorus levels) need to be aggressively treated.
- A rectal examination needs to be performed carefully to rule out distal obstruction and assess for melena. A rectal tube (a soft catheter such as a large indwelling catheter) can be inserted, which may help with decompression.
- Attention should be paid to the fluid status of the patient and appropriate resuscitation should be ensured.

Unless the patient has indications to immediately undergo surgical intervention (see the following), the next steps include:

- Serial abdominal examinations and abdominal radiographs with a focus on worsening pain, development of peritonitis, enlarging diameter of the colon, or presence of free air.
- Serial complete blood count (CBC) and lactate measurements, with particular attention to worsening leukocytosis, worsening anemia, and increasing lactic acidosis.
- Further workup to confirm the diagnosis (if not yet established), such as testing for *Clostridioides difficile (C. difficile)* and presence of CMV.
- If *C. difficile* infection is confirmed or suspected, empiric treatment for *C. difficile* should be initiated (see next section). For other etiologies, broad antibiotic coverage against gram-negative and anaerobic bacteria (eg, piperacillin/tazobactam) and/or specific treatment (ie, ganciclovir for CMV colitis) should be initiated.
- Mechanical obstruction as a cause of TM requires surgical or procedural intervention (see next section).

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Laxatives and motility agents are absolutely contraindicated because they might precipitate colonic perforation, and opioid pain medication *should be avoided or limited because it further diminishes intestinal motility.*

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E. Specific Management for Important Causes of Toxic Megacolon

1. *Clostridioides difficile* Infection

Medical management of severe *Clostridioides difficile (C. difficile)* infection with or without TM includes stopping causative antibiotics (if possible) and initiating specific antibiotic therapy against *C. difficile*. A 10-day course of either oral vancomycin or fidaxomicin is recommended for an initial infection. In fulminant, or severely ill and/or complicated infection, oral vancomycin is preferred. If patients have ileus and are unable to tolerate oral vancomycin, it can be administered rectally every 6 hours as a retention enema. While no longer recommended in mild *C. difficile* infection, IV metronidazole should be administered along with the oral or rectal vancomycin in patients with fulminant *C. difficile* infection. Patients who experience a recurrence of *C. difficile* infection should be managed with either a tapered and pulsed vancomycin regimen or 10 days of fidaxomicin (if not used for the initial episode). There is no evidence that longer courses of vancomycin or fidaxomicin are helpful, even in those with fulminant disease. For patients with multiple recurrences of *C. difficile* infection despite appropriate antibiotic treatment, fecal microbiota transplantation should be considered.

The mortality of advanced *C. difficile* infection with TM is excessive and there should be a low threshold for considering surgical intervention, despite the morbidity of a major operation. Patients with peritonitis or perforation have a clear indication for emergent operation, but those with severe leukocytosis (WBC more than 20,000/mm^3), worsening lactic acidosis, or septic shock without another obvious source, may also benefit from early surgical intervention. Among the risk factors for death were age 70 years or older, severe leukocytosis (35,000/mm^3) or leukopenia, and a need for vasopressors or mechanical ventilation. In the operating room, a subtotal colectomy (ie, leaving a short rectal stump behind) with end ileostomy is the current standard treatment. Due to the high morbidity and mortality of a subtotal colectomy, particularly in elderly and/or critically ill patients, other surgical strategies are being studied and used. The most promising of these consists of colonic lavage via loop ileostomy which allows for colonic preservation. There is, however, a risk of residual or recurrent *C. difficile* infection, and this novel approach should only be considered in experienced hands. In elderly, multi-morbid patients, a frank family discussion about expected outcomes and goals of care as well as involvement of the palliative care service, if available, are important.

2. Inflammatory Bowel Disease

The indications for emergent surgical intervention are similar as for other causes of TM and include impending perforation, peritonitis, worsening clinical examination and/or laboratory studies, or lack of improvement with optimal medical treatment within 48 to 96 hours. Colectomy should also be considered for persistent, intractable symptoms of IBD. Immunosuppressive medications can be part of the medical regimen of patients with IBD and obscure their presentation by preventing the development of severe leukocytosis or clear signs of peritonitis.

For medical management, consultation of the specialty service for IBD (often gastroenterology or colorectal surgery) should be initiated early to optimize medical management. Initial treatment includes IV steroids such as hydrocortisone or methylprednisolone, while medications for maintenance therapy, such as sulfasalazine and 5-ASA compounds, are not used in TM. Immunomodulators may be used if conventional medical therapy fails.

3. Mechanical Obstruction

TM as a result of mechanical obstruction suggests a late presentation. Rectal examination or, more frequently, imaging such as abdominal radiograph or CT scan will suggest an obstructing mass (eg, due to cancer or a benign stricture) or volvulus. Whereas a sigmoid volvulus can be decompressed colonoscopically followed by non-emergent surgical colectomy, any volvulus causing TM, or any complete colonic obstruction due to a mass is a surgical emergency. In select cases of obstructing masses, colonoscopic stenting can be an option, while surgical therapy consists of partial or total colectomy. In frail patients who are considered to be poor candidates for colectomy, decompressive loop colostomy is an option to provide temporary decompression.

III. SMALL BOWEL OBSTRUCTION

Case Study

A 75-year-old woman with a history of hypertension and type 2 diabetes mellitus arrives to the emergency department reporting abdominal pain for the past 3 days associated with nausea and vomiting. Her last bowel movement was 4 days ago. Her vital signs reveal a blood pressure of 90/68 mm Hg, heart rate of 110 beats/min, respiratory rate of 24 breaths/min, and temperature of 38° C (100.4° F). Her oxygen saturation on room air is 90%, but she reports dyspnea only with exertion. Her oxygen saturation increased to 96% on 2 liters of oxygen. You are called to evaluate her.

- Based on patient clinical findings, what are the potential differential diagnoses?
- What tests are indicated immediately?

A. Introduction

Small bowel obstruction (SBO) is a common reason for consultation in the emergency department and inpatient setting. The presentations range from mild abdominal distension and nausea to peritonitis and critical illness. Morbidity and mortality rates rise dramatically in the setting of bowel ischemia, requiring immediate recognition and treatment. Prompt and detailed clinical history, early recognition, and intervention are keys to minimizing morbidity and mortality. Clinical presentation and radiographic findings both need to be considered when making management decisions because they do not necessarily correlate.

B. Etiology

There are three main causes of SBO. In Western countries the most common cause is adhesive disease, accounting for 65% to 75% of cases. While there are a very small number of patients who can have adhesions in the absence of prior abdominal surgeries, in general, the diagnosis of adhesive SBO should not be made in the absence of an abdominal surgical history. The second most important cause of SBO is hernias (often ventral and inguinal, but also including internal hernias without obvious findings on examination). In developing countries, hernias are the leading cause of SBOs with the third important cause being malignancy. Other less common causes of SBO include inflammatory bowel disease, intussusception, volvulus, gallstones, trauma, foreign bodies, and bezoars.

C. Types

SBO can be categorized as partial, high-grade, complete, or closed-loop. The risk of bowel compromise and need for surgical management increase with worsening degree of obstruction (a true closed-loop obstruction requires immediate surgical attention), but general clinical presentation is more important than radiographically determined degree of obstruction. More recently, there have been attempts to develop a systematic approach to categorize the clinical findings, severity, and outcomes.

Complete bowel obstruction is a complete occlusion of the lumen without allowing a path for gas or abdominal fluid content to pass at the obstruction site.

Partial bowel obstruction is the narrowing at the site of the obstruction of the lumen; gas and abdominal fluid content are still able to pass at some level.

Closed-loop bowel obstruction is a segment of bowel that is obstructed at two points preventing prograde and retrograde decompression. This leads to a rapid increase in intraluminal pressure, distension, ischemia, and perforation if not addressed urgently.

D. Initial Assessment

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Hemodynamic instability, organ failure, severe leukocytosis, and lactic acidosis are concerns for bowel ischemia and a surgical consult should be obtained immediately.

Initial assessment of an SBO needs to focus on ruling out intestinal strangulation or presence of irreversible bowel ischemia, both of which require emergent surgical exploration. The physical examination includes determining the degree of abdominal distension, pain, or presence of peritonitis. Hemodynamic instability, organ failure, severe leukocytosis, and lactic acidosis are concerns for bowel ischemia and a surgical consult should be obtained immediately. Patients also need to undergo a thorough examination from "head-to-toe" to detect ventral, flank, inguinal, or femoral hernias. Initial assessment and evaluation of a patient's fluid status is essential in SBO because most patients are severely dehydrated with concomitant acute kidney injury.

E. Diagnosis

1. Radiographic Examinations

Radiographic examinations are critical to the diagnosis and severity of SBO. Initial imaging studies include supine or upright abdominal radiographs. Lateral decubitus radiographs or an upright chest radiograph can rule out the presence of free air (ie, perforation). Small bowel dilation (**Figure 13-3A** and **13-3B**), multiple air-fluid levels in the small bowel, or a "string of beads" sign suggest the diagnosis of SBO.

Figure 13-3A and **13-3B.** Small Bowel Dilatation

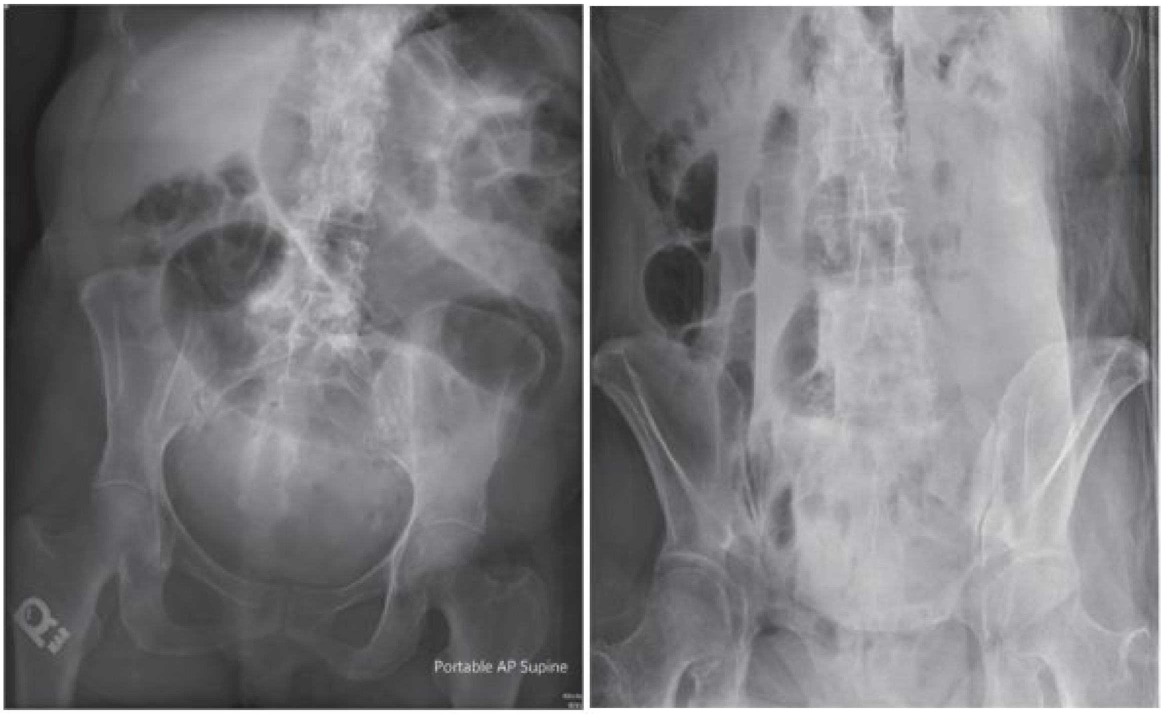

Image courtesy of S. Leichtle, MD, FACS   Image courtesy of S. Bonebrake, DO

A CT scan of the abdomen and pelvis with IV contrast is the best imaging modality to assess a patient with suspected SBO with high sensitivity and specificity. The classic CT appearance of an SBO includes a lead point with small bowel dilatation proximally and decompression distally (**Figure 13-4**).

Figure 13-4. Small Bowel Obstruction with Transition Point (arrow)

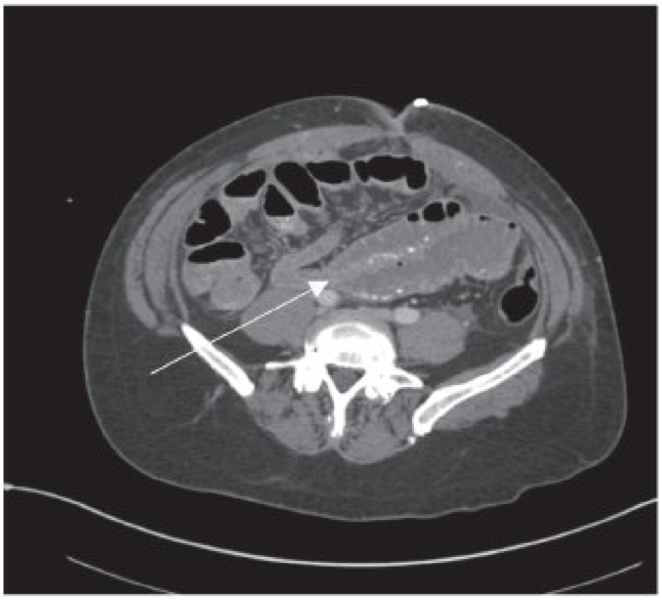

Image courtesy of S. Leichtle, MD, FACS

However, often a clear transition point cannot be visualized on imaging. CT imaging can also demonstrate mesenteric swirling or a C-shaped segment of small bowel concerning for closed-loop obstruction. An abdomen/pelvis CT can also detect hernias as a cause of the SBO that might have been missed on physical examination (ie, a femoral hernia or internal hernia). CT with IV contrast should be given whenever possible because it allows for the detection of ischemic bowel, characterized by increased bowel wall thickness or pneumatosis.

Other radiographic examinations may include fluoroscopic small bowel follow through (SBFT) or abdominal radiograph with water-soluble oral contrast. These should only be performed in clinically stable patients in whom perforation has been ruled out. These examinations provide further evaluation of the degree of the bowel obstruction and there may be therapeutic benefit, the latter remains controversial.

2. Laboratory Examinations

Routine laboratory assessment should include a CBC, basic metabolic panel, and lactate level. Coagulation panel and type and screen should be added if surgical intervention is likely. Severe, persistent, or worsening leukocytosis and/or lactic acidosis in the presence of a SBO are concerning for ischemic bowel and should prompt surgical consultation. Most patients with SBO have electrolyte abnormalities and are dehydrated due to nausea, emesis, and inadequate oral intake. They often present with acute kidney injury and may have hyperkalemia. A basic metabolic panel in addition to calcium, magnesium, and phosphorus levels is important to obtain to address these abnormalities. An infrequent cause of SBO is "gallstone ileus," in which imaging and an abnormal hepatic panel are helpful in this case.

F. Management

1. Nonsurgical Management

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Patients with SBO and little improvement after 48–72 hours of nonsurgical management or worsening clinical examination and/or laboratory studies should strongly be considered for surgical consultation.

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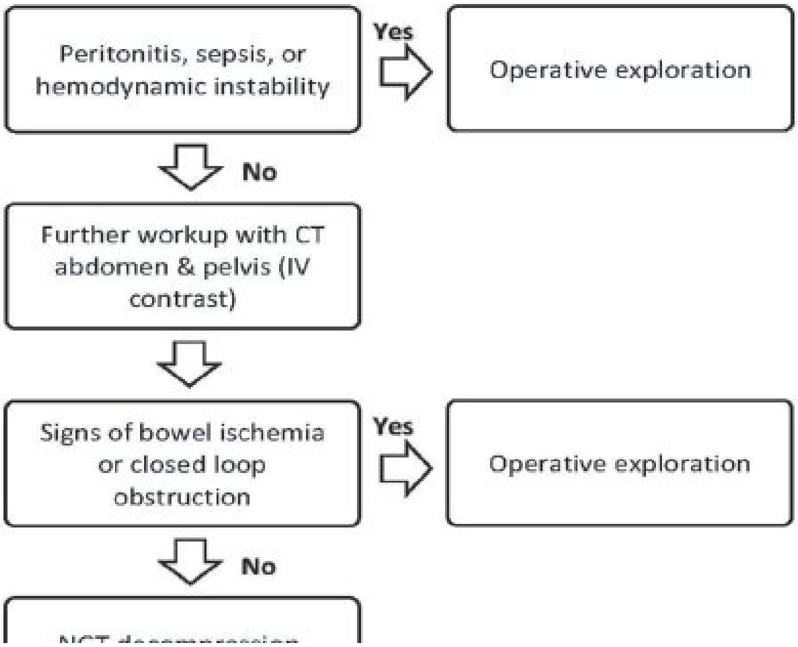
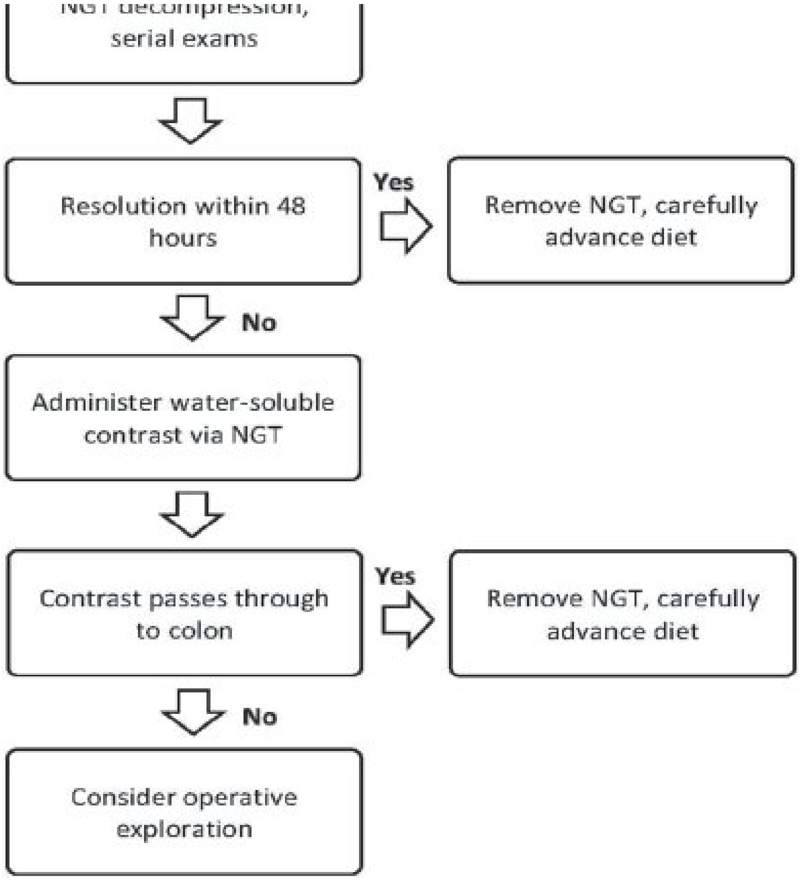
Nonsurgical patients with SBO should have strict NPO status and placement of a nasogastric tube to decompress the gastrointestinal (GI) tract, resuscitation with balanced crystalloid solutions such as lactated ringer solution, and correction of electrolyte imbalances. Acute kidney injury due to dehydration is often present and patients are at risk for electrolyte abnormalities and fluid overload. Patients with SBO and little improvement after 48–72 hours of nonsurgical management or worsening clinical examination and/or laboratory studies should strongly be considered for surgical consultation. Nontoxic patients with adhesive obstruction etiology who do not improve early in their course may be candidates for enteral hypertonic water-soluble contrast challenge which can be therapeutic by decreasing bowel wall edema and stimulating bowel peristalsis.

2. Surgical Management

Most patients requiring surgical management of their SBO are comprised of those who either failed to respond to nonsurgical management or had findings concerning for bowel ischemia on initial presentation. Either exploratory laparotomy or diagnostic laparoscopy is the surgical intervention. The latter is absolutely contraindicated in patients with hemodynamic instability. Relative contraindications to laparoscopic (ie, minimally invasive) exploration are severe bowel distension, multiple prior abdominal surgeries, and lack of experience with advanced laparoscopy. Preoperatively, patients (or their families) need to be informed that extensive bowel resection, stoma creation, and further reoperations might be necessary. Patients with extensive bowel necrosis might be dependent on total parenteral nutrition postoperatively, and some patients might have surgical findings not compatible with curative treatment. Fortunately, in many patients, lysis of adhesions or sometimes transection of a single adhesive band can resolve their SBO and postoperative recovery can be fast. Patients with SBO due to hernias require reduction of their hernia, possible bowel resection, and hernia repair, depending on the type of hernia and intraoperative findings (**Figure 13-5**).

Figure 13-5. Summary and Algorithm for Management of Small Bowel Obstruction


Peritonitis, sepsis, or hemodynamic instability
Yes
Operative exploration
No
Further workup with CT abdomen & pelvis (IV contrast)
Signs of bowel ischemia or closed loop obstruction
Yes
Operative exploration
No


NGT decompression,
serial exams
Resolution within 48 hours
Yes
Remove NGT, carefully advance diet
No
Administer water-soluble contrast via NGT
Contrast passes through to colon
Yes
Remove NGT, carefully advance diet
No
Consider operative exploration

Postoperatively, patients need to be monitored closely. Even after successful lysis of adhesions or reduction of a hernia, they are at risk for postoperative ileus, delayed development of missed ischemic bowel, and abdominal compartment syndrome. The latter is of particular concern in patients who underwent aggressive fluid resuscitation.

IV. PERITONITIS

Case Study

A 58-year-old man with a history of diverticulosis presents with diffuse abdominal pain, nausea, vomiting, and fever. He reports a preceding 5-day history of worsening nausea, abdominal discomfort predominantly in the left lower abdomen, and malaise. On examination, he has a diffusely tender abdomen with guarding.

- What is the patient's likely diagnosis based on his clinical findings?
- What diagnostic studies are indicated?

A. Definition

Peritonitis is defined as inflammation of the peritoneum. It can be classified into primary, secondary, and tertiary peritonitis.

Primary Peritonitis – often referred to as spontaneous bacterial peritonitis (SBP). It can occur from spontaneous bacterial invasion of the peritoneal cavity and usually occurs in the immunocompromised individual such as a patient with cirrhosis.

Secondary Peritonitis – peritoneal infections secondary to an intra-abdominal source such as hollow viscus perforation, necrotic bowel, nonbacterial peritonitis, or penetrating infectious process. This is the most common form of peritonitis.

Tertiary Peritonitis – characterized by persistent or recurrent infections after adequate initial therapy. It usually follows after surgical attempts to treat secondary peritonitis and can be seen in the immunocompromised patient.

B. Etiology and Pathogenesis

1. **Primary peritonitis** – diffuse bacterial infection without the loss of the GI tract integrity. The highest risk is among patients with decompensated liver cirrhosis. Approximately 10–30% of patients with cirrhosis and ascites develop SBP. In most cases, SBP is due to a single organism. The presence of multiple organisms should raise concern for the presence of secondary rather than primary peritonitis. The most common gram-negative bacteria include *E. coli* (40%), followed by *Klebsiella pneumonia, Pseudomonas aeruginosa, Proteus* species, and other gram-negative bacteria. Frequent gram-positive organisms include *Streptococcus pneumoniae* and other

Streptococcus species (30%), as well as *Staphylococcus* species. Less than 5% of SBP are due to anaerobic organisms.

2. **Secondary peritonitis** – acute peritoneal infection due to loss of GI tract integrity or from an inflamed or infected abdominal organ. This can be the result of hollow viscus perforation, such as perforated sigmoid diverticulitis, an anastomotic leak in the postoperative setting, or due to severe inflammation of an abdominal organ such as gangrenous cholecystitis. Secondary peritonitis can be localized, ie, the “classic” right lower quadrant pain in acute appendicitis, or diffuse. The latter indicates spread of the infection throughout the abdominal cavity and urgent need for source control.

Most common gram-negative organisms to cause secondary peritonitis include *E. coli* (60%), followed by *Enterobactor/Klebsiella* species, *Proteus* species, and *Pseudomonas aeruginosa*. Gram-positive organisms include *Streptococci* species (28%), followed by *Enterococci* species, and *Staphylococci* species. The most common anaerobic organisms to cause secondary peritonitis are anaerobes which include *Bacteroides* (72%), *Clostridioides, Peptostreptococcus*, and *Peptococcus*. *Candida* species accounts for 2% of cases. In secondary peritonitis, multiple organisms are usually found in the peritoneal fluid (**Table 13-1**).

> !
>
> *The vast majority of primary peritonitis is due to a single organism.*
>
> !

3. **Tertiary peritonitis** – more commonly occurs in patients who are immunocompromised and those with significant preexisting comorbidities. It usually follows an attempt to surgically treat secondary peritonitis and is almost exclusively associated with a systemic inflammatory response.

4. **Chemical peritonitis** – Sterile peritonitis caused by irritants such as bile, blood, barium, or other substances or by transmural inflammation of visceral organs such as in Crohn’s disease without introduction of bacteria into the peritoneal cavity.

C. Diagnosis

The diagnosis of peritonitis is primarily clinical. Patients can have focal, localized peritonitis with voluntary guarding on palpation, or diffuse abdominal pain with rebound tenderness and abdominal rigidity. Associated symptoms are often anorexia, nausea, vomiting, diarrhea, fever, tachycardia, and tachypnea. The latter symptoms can indicate the presence of septic shock, particularly in the setting of concomitant metabolic acidosis, hypotension, and other organ system failure.

A high gradient serum ascites albumin gradient (SAAG >1.1 g/dL) indicates portal hypertension and suggests a nonperitoneal cause of ascites.

Radiologic tests to affirm the diagnosis of secondary peritonitis can include plain abdominal radiographs (assessment for free air), ultrasound (demonstrating an inflamed abdominal organ such as appendix), and CT scan of abdomen and pelvis. Laboratory tests include complete blood count (CBC), comprehensive metabolic panel, lactate, and blood cultures.

Table 13-1 Common Causes of Secondary Peritonitis by Regions of the Body

Regions	Causes
Esophagus (abdominal portion)	Boerhaave syndrome Malignancy Penetrating trauma Iatrogenic*
Stomach	Peptic ulcer perforation Malignancy Penetrating trauma Iatrogenic*
Duodenum	Peptic ulcer perforation Blunt and penetrating trauma Iatrogenic*
Biliary tract	Cholecystitis Gallstone ileus or stone perforation Malignancy Penetrating trauma Iatrogenic*
Pancreas	Pancreatitis (alcohol, drugs, gallstone) Blunt and penetrating trauma Iatrogenic*
Small bowel	Ischemia Incarcerated hernia Crohn's disease Meckel's diverticulum Penetrating trauma Closed loop obstruction
Large bowel and appendix	Ischemia Diverticulitis Malignancy Ulcerative colitis and Crohn's disease Appendicitis Penetrating trauma Colonic volvulus Iatrogenic*
Uterus, salpinx, and ovaries	Pelvic inflammatory disease Malignancy (rare) Trauma (uncommon)

*Iatrogenic trauma can result from endoscopic procedures.

If there is concern for primary peritonitis (SBP) and imaging workup is not suggestive of secondary peritonitis, paracentesis should be performed prior to administering antibiotics. The ascitic fluid should be tested for the following:

- Aerobic and anaerobic culture (use blood culture bottles)
- Cell count and differential
- Gram stain
- Albumin
- Protein
- Glucose
- Lactate dehydrogenase (LDH)
- Amylase
- Bilirubin (if fluid is dark orange or brown)

An elevated ascitic fluid absolute polymorphonuclear cell neutrophil (PMN) count ≥ 250 cells/mm^3, a positive bacterial culture, and absence of secondary causes of peritonitis, such as bowel perforation, suggest SBP.

D. Management

Source control is the single most important step in the treatment of peritonitis. In addition, patients need to undergo prompt antibiotic administration and appropriate fluid resuscitation.

1. **Fluid resuscitation** – Fluid resuscitation with crystalloids, supplemented by vasoactive medications, and following current sepsis treatment guidelines should be initiated promptly. The treatment strategy should be tailored to the individual patient and adjusted based on patient response.

2. **Source Control** – Elimination of the source of infection is the single most important step in the treatment of peritonitis. Depending on the etiology, this may include surgical intervention, placement of percutaneous drains, or administration of broad antibiotic coverage. Managing source control early is important in preventing severe adverse consequences. Determining whether the intra-abdominal infection is uncomplicated (limited to a single organ) or complicated (spread to involve the entire abdominal cavity) can be helpful when deciding on how aggressive treatment needs to be, but most importantly requires individual patient assessment and early surgical consultation.

3. **Antimicrobial Therapy** – The choice of antibiotics should be based on the patient's clinical condition, risk for multidrug-resistant bacteria, and the local resistant epidemiology. In critically ill patients, antibiotic coverage should be broad initially, and then tailored to specific micro-organisms once this information becomes available. First choice in patients, even critically ill but somewhat stable, is either cefotaxime or ceftriaxone. Beta-lactam/beta-lactamase inhibitor combinations and carbapenems are effective against gram-positive, gram-negative, and anaerobe organisms. For severe infections, piperacillin/tazobactam, meropenem, or the combination of a third- or fourth-generation cephalosporin or ertapenem with metronidazole are common empiric regimens. Ceftazidime and cefoperazone are third-generation cephalosporins with antipseudomonal coverage. Eravacycline is a viable option for complicated infections where *P. aeruginosa* is not a concern, particularly in patients with beta-lactam allergies or in those with extended spectrum betalactamase (ESBL) infections. It has a wide spectrum of activity including many ESBL and carbapenemase-producing organisms, anaerobes, *Acinetobacter baumannii*, methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant *Enterococcus* (VRE). Ciprofloxacin and levofloxacin are no longer first-line treatment in many geographic regions due to a prevalence of fluoroquinolone resistance. However, fluoroquinolones can be used for patients with an allergy to beta-lactams but only in combination with metronidazole. Eravacycline is a viable treatment for complicated infections due to its favorable activity against anaerobic

organisms, enterococci species, several extended-spectrum beta-lactamase (ESBL) and carbapenemase-producing Enterobacteriaceae, and *Acinetobacter* species.

!

The single most important step in the treatment of peritonitis is source control.

!

In patients who underwent source control of uncomplicated intra-abdominal infections such as non-perforated appendicitis or cholecystitis, postoperative antibiotic coverage is not recommended. In patients with complicated intra-abdominal infection who have undergone source control via surgical interventions, a 3- to 5-day course of antibiotics postoperatively is recommended. Patients with ongoing sepsis or peritonitis beyond 5 to 7 days of antibiotic treatment should warrant a diagnostic investigation. Single or multiple antibiotic regimens may be used.

V. BILIARY EMERGENCIES

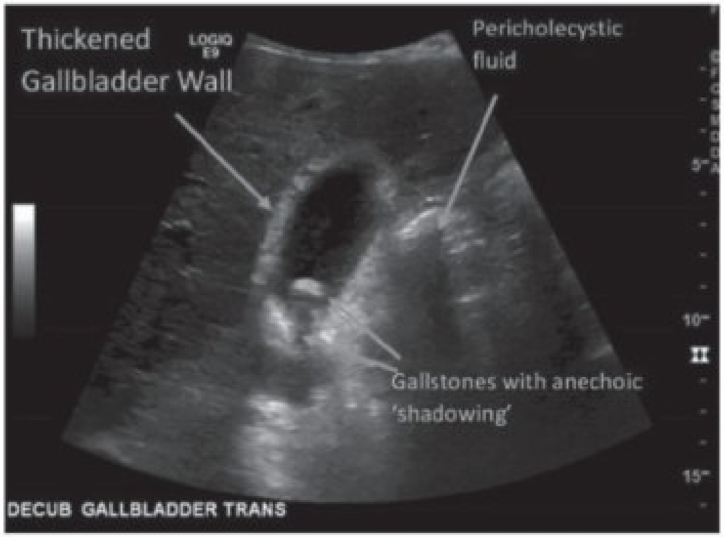
A. Introduction

Diseases of the gallbladder and biliary system are among the most commonly encountered urgent and emergent surgical problem. Presentations range from infectious or inflammatory problems, such as gallstones, pancreatitis, or cholangitis, to the result of external or iatrogenic trauma. Patients' acuity can range from minor abdominal discomfort to life-threatening critical illness, ie, in cases of severe pancreatitis with a mortality of 15% to 20%. These patients are commonly managed in an ICU setting.

B. Initial Assessment

Patients presenting with the severe forms of gallbladder and pancreas-related disease such as cholangitis or necrotizing pancreatitis are at risk for distributive and/or hypovolemic shock, septic, and sometimes hemorrhagic shock. In addition, patient condition is often worsened as a result of dehydration from vomiting and poor oral intake. Rapid assessment and source control are essential. The preferred resuscitation solution for septic and/or hypovolemic shock is balanced crystalloids. Concomitantly with resuscitation, patients must undergo investigation to determine the etiology of the biliary disease. Laboratory tests, diagnostic imaging, and a patient's history and events leading up to presentation (duration of pain) should be used to quickly determine the etiology and guide further treatment. Depending on the level of instability, diagnostic imaging will range from abdominal ultrasound (**Figure 13-6**), which can be easily performed at the bedside in the ICU, to CT and hepatobiliary scintigraphy (HIDA), or magnetic resonance imaging (MRI). The latter can only be performed safely in hemodynamically stable patients. Invasive procedures, such as endoscopic retrograde cholangiography (ERCP), cholangiography, and/or endoscopic ultrasound (EUS), may be beneficial. Determination regarding the patient's tolerance for these procedures must be made before they are performed.

Figure 13-6. Ultrasound Diagnosis of Cholecystitis: Presence of Gallstones, GB Wall Thickening, and Pericholecystic Fluid


Thickened Gallbladder Wall
LOGIQ E9
Pericholecystic fluid
5
10
15
Gallstones with anechoic 'shadowing'
DECUB GALLBLADDER TRANS

Abnormal gallbladder ultrasound consistent with acute calculous cholecystitis. Image courtesy of Mary Jane Reed, MD

1. Cholecystitis and Cholangitis

Acute calculous cholecystitis typically presents with right upper quadrant pain. Diagnostic workup reveals systemic signs of inflammation such as fever or elevated WBC and imaging characteristics of cholecystitis. According to the Tokyo Guidelines 2018, patients with grade I (mild) or grade II (moderate) acute cholecystitis should undergo early laparoscopic cholecystectomy, and barring unforeseen complications, these patients are unlikely to be ICU patients. Patients who have cholecystitis that goes unrecognized may develop grade III cholecystitis. These patients should wait to undergo cholecystectomy until they have been resuscitated and organ dysfunction is reversed. In the face of prohibitive surgical risk, including persistent organ failure, cholecystectomy should be deferred in favor of treatment with antibiotics and percutaneous cholecystostomy. Patients with grade III acute cholecystitis are patients with cholecystitis and concomitant organ dysfunction (**Table 13-2**). Patients with untreated cholecystitis may also develop: 1) gallbladder empyema, where the distended gallbladder is filled with pus, 2) emphysematous cholecystitis, gas in the wall of the gallbladder, 3) perforation, or 4) gallbladder torsion. Any of these can result in severe sepsis and carry much higher mortality. Early surgical consultation to determine the best course of management in a collaborative fashion is highly recommended and the Tokyo Guidelines may not be appropriate for every patient.

> *In patients with cholecystitis or cholangitis, early surgical consultation is highly recommended.*

Table 13-2 Severity Grading for Acute Cholecystitis

Severity Grading for Acute Cholecystitis According to Tokyo Guidelines*

Grade	**Criteria**
Mild (grade I)	Acute cholecystitis that does not meet the criteria for a more severe grade Mild gallbladder inflammation, no organ dysfunction
Moderate (grade II)	The presence of one or more of the following: • Elevated white-cell count (>18,000 cells per cubic millimeter) • Palpable, tender mass in the right upper quadrant • Duration >72 hr • Marked local inflammation including biliary peritonitis, pericholecystic abscess, hepatic abscess, gangrenous cholecystitis, emphysematous cholecystitis
Severe (grade III)	The presence of one or more of the following: • Cardiovascular dysfunction (hypotension requiring treatment with dopamine at ≥5 µg per kilogram of body weight per minute or any dose of dobutamine) • Neurologic dysfunction (decreased level of consciousness) • Respiratory dysfunction (ratio of partial pressure of arterial oxygen to the fraction of inspired oxygen <300) • Renal dysfunction (oliguria; creatinine level, >2.0 mg/deciliter) • Hepatic dysfunction (prothrombin time-international normalized ratio, >1.5) • Hematologic dysfunction (platelet count, <100,000 per cubic millimeter)

From *N Engl J Med.*, Strasberg SM, Acute Calculous Cholecystitis, 358, 2804-2811. Copyright © 2008 Massachusetts Medical Society. Reprinted with permission from Massachusetts Medical Society.

2. Acalculous Cholecystitis

> *Acalculous cholecystitis is serious and an uncommon complication seen in septic, immunocompromised, or otherwise critically ill patients.*

Acalculous cholecystitis (ACC) is an uncommon and serious complication seen in septic, immunosuppressed, or otherwise critically ill patients. Risk factors are male sex, diabetes mellitus, vascular disease, and injury due to external trauma or systemic stressors such as burns or the major surgical interventions. The pathogenesis is a combination of bile stasis related to the NPO state combined with hypoperfusion. The hypoperfusion may be related to intravascular depletion or related to vasoactive medications. It may also be related to intra-abdominal hypertension or gallbladder distension causing local ischemia. Diagnosis can be difficult. Patients may or may not be able to report pain depending on level of consciousness and sedation. Physical examination may be unreliable for the same reason. Fevers and WBC and liver function tests (LFTs) elevations may be attributed to other causes as well. The primary imaging test of choice is ultrasound, which can be performed at the bedside of a critically ill patient and will demonstrate signs of acute cholecystitis without the presence of gallstones. Ultrasound in this setting has good sensitivity and excellent specificity. A HIDA scan not only has a high false-negative rate in ACC, but also requires a significant period out of the ICU, so this modality should be used with caution. CT scans are an alternative to ultrasound and may be helpful to rule out other causes of acute illness. Because ACC is most often found in critically ill patients, organ dysfunction is typically present, and therefore patients are not candidates for laparoscopic cholecystectomy. Percutaneous cholecystostomy tube placement and antibiotics are the treatment of choice, but open cholecystectomy might be required in patients with gangrenous or necrotic gallbladder to achieve source control.

3. Acute Cholangitis

Acute cholangitis is defined as acute inflammation and infection of the biliary tree. This is most commonly a consequence of bile duct obstruction and subsequent bacterial proliferation in the bile. As with all infections, avoiding systemic progression is the key to improving survival. Charcot's triad (fever, jaundice, and right upper quadrant pain) has long been considered the hallmark of cholangitis. The Tokyo Guidelines for diagnosis require systemic inflammation and either cholestasis or specific findings on imaging for a suspected diagnosis, and all three for a definitive diagnosis. Using these criteria in the appropriate clinical situations resulted in 91.8% sensitivity and 77.7% specificity for cholangitis. Management includes resuscitation, hemodynamic monitoring, NPO, and antibiotics. Diagnostic imaging is used to identify the etiology and location of the obstruction. Maneuvers should be undertaken to address the obstruction as soon as the patient can tolerate an intervention. This is usually endoscopic retrograde cholangiopancreatography (ERCP) decompression or percutaneous transhepatic cholangiography and drainage.

4. Biliary Injury

Hemobilia is gastrointestinal hemorrhage emanating from a lesion or injury in the biliary tree. In most studies, trauma, including blunt and penetrating, iatrogenic, and accidental, is the most common etiology of bleeding. Other causes include inflammation, tumors, and vascular conditions. Patients may possibly present with Quincke's triad which includes abdominal pain, gastrointestinal bleeding, and jaundice.

The diagnosis of hemobilia can be difficult because bleeding is often intermittent. Patients with gastrointestinal hemorrhage often undergo upper endoscopy which can reveal the diagnosis if blood is seen coming from the ampulla of Vater. Other imaging, such as ultrasound and CT, may reveal layering and filling defects in the gallbladder and bile ducts due to blood and clots. The patient may require active resuscitation from shock. The key to successful management of hemobilia is recognition and prompt angioembolization by interventional radiology.

5. Bile Duct Injury

Postoperative bile duct injury is a serious complication of upper abdominal operations and can occur even in “routine” laparoscopic cholecystectomies. Injury is often not immediately recognized and delayed presentations may be severe with bile leak, cholangitis, and severe sepsis. After appropriate resuscitation, the next step involves early surgical consultation to establish a surgical plan. This will include draining abdominal fluid collections and major hepatobiliary reconstruction to restore the flow of bile.

VI. ESOPHAGEAL PERFORATION

A. Introduction

Esophageal perforation can rapidly progress to life-threatening sepsis and death. Rapid stabilization and early intervention to establish source control are essential. Individual or institutional inexperience with this condition may result in a delay in diagnosis, dramatically increasing rates of morbidity and mortality. Early recognition is facilitated by a high index of suspicion based on patient history and prompt recognition of signs and symptoms on examination and imaging.

B. Etiology of Esophageal Perforation

1. Spontaneous

Spontaneous esophageal perforation is generally due to sudden high intraluminal pressure. The classic example is Boerhaave syndrome, where prolonged or forceful retching causes a transmural rupture, usually in the distal esophagus just proximal to the gastroesophageal junction. Sepsis is due to contamination of the mediastinum, left pleural space, or drainage into the peritoneum. Other mechanisms of esophageal perforation include weakened tissue due to erosion of ulcers, infection, immunodeficiency, or chemoradiation.

2. Foreign Body

While foreign body ingestion is relatively common, it results in perforation in only about 1–2% of cases. Foreign body perforations are more likely in the cervical esophagus, one of the areas of physiologic narrowing of the esophagus. As a result, cervical esophageal perforations are typically less morbid because there is more access for drainage and the spread of infection can be limited.

3. Iatrogenic

Due to the increase in endoscopic procedures, iatrogenic perforation is an important etiology of esophageal perforation. Unrecognized intra-operative laceration of the esophagus is rare, but procedures associated with this type of esophageal perforation include:

- Operations at the hiatus such as fundoplication, vagotomy, and hiatal hernia repair
- Operations in the mediastinum including lung transplantation, pneumonectomy, and thoracic aortic aneurysm repair
- Cervical operations such as thyroidectomy, tracheostomy, mediastinoscopy, and cervical spine surgery

The key to optimal outcome is immediate recognition of the injury because any delay in treatment, particularly beyond 24 hours, dramatically increases morbidity and mortality rates.

4. Trauma

Most esophageal injuries are penetrating injuries. The incidence of blunt esophageal injuries is very low. The most common penetrating etiology is gunshot wound (75%) in the United States, followed by stab wounds, and other mechanisms. Suspicion should always be high for esophageal or hypopharyngeal injury in any penetrating wound to the lower head or neck, particularly zones I and II of the neck.

C. Presentation

Esophageal perforation often presents with nonspecific symptoms such as chest pain, dysphagia, dyspnea, subcutaneous emphysema, epigastric pain, fever, tachycardia, and tachypnea. The two pathognomonic signs of esophageal perforation are Hamman's sign and Mackler's triad. Hamman's sign is a rasping or crunching heard on auscultation over the precordium caused by the heartbeat against air-filled tissue. Mackler's triad is chest pain, vomiting, and subcutaneous emphysema. These "classic presentations" are rare. Subcutaneous emphysema, while a highly suspicious finding, is detectable by physical examination in only 30% of patients after thoracic perforation and 60% of patients after cervical perforation.

Patients with cervical perforations can present with neck pain, dysphonia, hoarseness, and cervical dysphagia. Acute chest pain, back pain, or pain that radiates to the back is more likely a mid-esophageal injury and peritoneal signs correspond to intraperitoneal injuries. Signs of an inflammatory response sepsis, such as tachycardia, tachypnea, elevated white blood cell count, and fever, can develop in any esophageal injury and represent the development of sepsis. This is an ominous development. A CT scan of the neck and chest demonstrating a large amount of subcutaneous air in the setting of penetrating trauma is highly suspicious of esophageal trauma.

D. Diagnosis

Prompt diagnosis of esophageal perforation can be difficult due to its nonspecific symptoms. The median time to diagnosis of esophageal perforation can be up to 12 hours (range 1–120 hours), with a high index of suspicion and attention to detail being important for a successful diagnosis. In a recent review, odynophagia and dysphagia were the most common presenting symptoms. Particular attention should be paid to patients with risk factors for perforation such as trauma, instrumentation, or foreign body ingestion. These patients need further evaluation.

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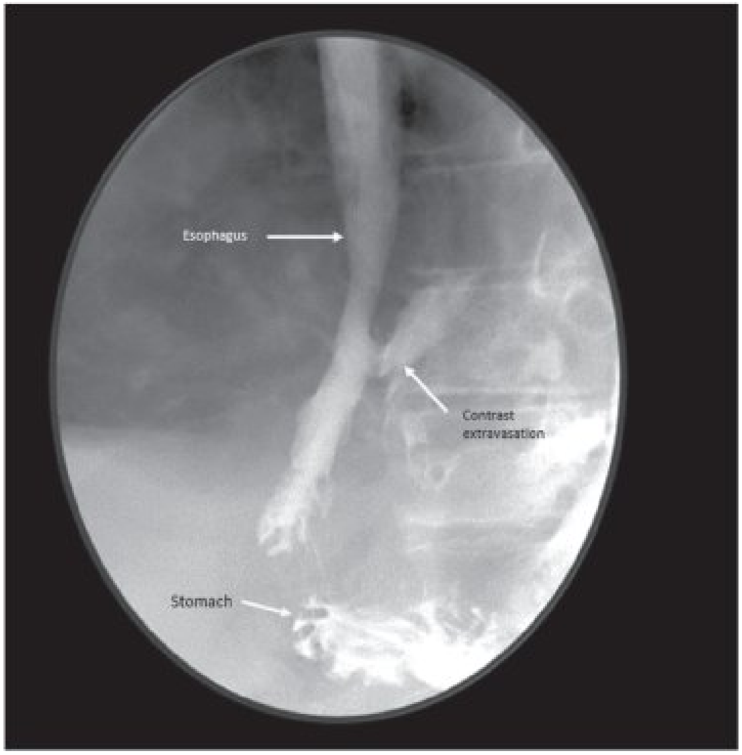
Prompt diagnosis of esophageal perforation can be difficult due to nonspecific symptoms. A high index of suspicion and attention to detail are important.

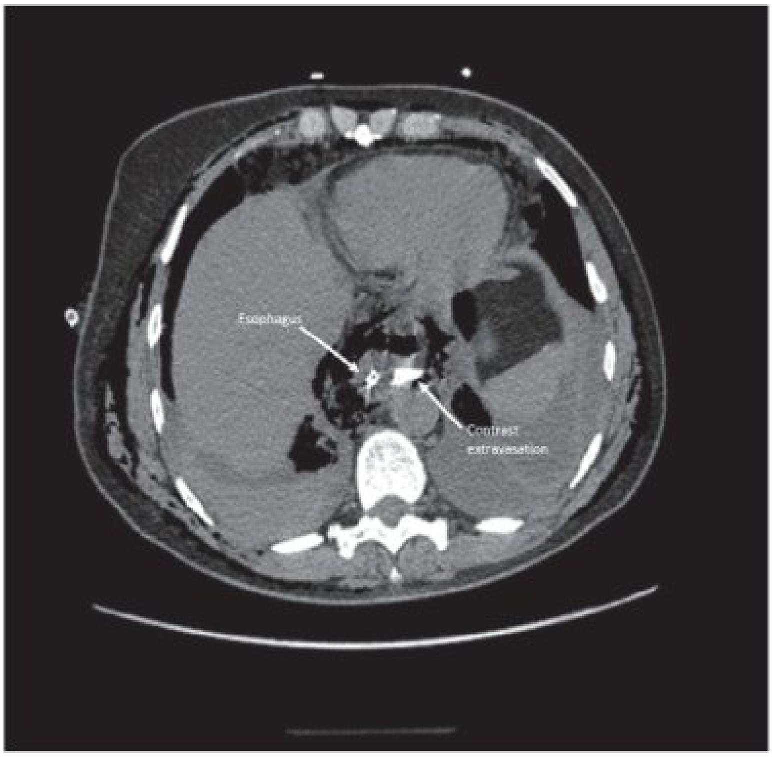
Evaluation begins with plain chest radiographs in which signs of esophageal injury may include pleural effusion (mostly on the left), pneumomediastinum, subcutaneous emphysema, or pneumothorax. A swallow study with water-soluble contrast medium (if the patient can swallow) is the next step and will reveal a contrast leak in most cases of esophageal perforation (**Figure 13-7**). Water-soluble contrast should be used instead of barium contrast to prevent barium-related inflammation of the mediastinum if there is perforation. If the water-soluble contrast study is negative for an obvious leak, it can be followed by a swallow study with diluted barium for optimal sensitivity. CT is frequently used in patients who cannot undergo esophagography (**Figure 13-8**). Patients who are unable to swallow or who are critically ill may proceed directly to CT. Patients who have other injuries and who may need CT for other reasons may forgo esophagography in favor of CT. This may be beneficial in preoperative planning, and findings in esophageal perforation are similar to plain film findings and include pleural effusion, pneumomediastinum, subcutaneous emphysema, and pneumothorax.

There is significant controversy regarding the use of endoscopy to identify perforation. In evaluating penetrating esophageal injury, endoscopy has been shown to have a sensitivity of 100% and specificity of 83%. In foreign body perforation, laryngoscopy and flexible endoscopy had long been considered the standard for diagnosis, but recently have been shown to miss a number of foreign bodies, particularly fish bones, which were identified by CT. Flexible esophagoscopy is generally avoided when other forms of injury are suspected due to the potential risk to convert a small or partial tear into a larger laceration.

Figure 13-7 and **13-8.** Esophageal Perforation


Esophagus
Contrast extravasation
Stomach

(Figure 13-7) Extraluminal contrast on esophagography. Used with permission. Courtesy of Matthew A. Facktor, MD



(Figure 13-8) Contrast extravasation into mediastinum consistent with esophageal perforation.
Used with permission. Courtesy of Matthew A. Facktor, MD

E. Management

The management in esophageal perforation begins with resuscitation and the principles of critical care. There is the potential for airway compromise due to an expanding hematoma or abscess. The airway should be evaluated and secured prior to any other intervention. There may be an empyema, pleural effusion, or pneumothorax interfering with respiration. Adequate gas exchange must also be ensured. The patient may already show signs of sepsis with circulatory compromise. Hemodynamic monitoring should be initiated. Lactate levels should be monitored. It is likely that fluid resuscitation will be required to restore circulating blood volume.

Identifying and controlling the source of ongoing contamination is the next step. It is critical to avoid further spillage and to try to remove any spillage from the perforation that has already occurred. If chest radiographs reveal pleural effusions or pneumothorax, it is likely that tube thoracostomy will be required. This may be accomplished in the emergency department or ICU, or in a procedures or operating area depending on the facility and the next steps. Aside from tube thoracostomy, all other interventions to control mediastinal, pleural, cervical, or peritoneal contamination would likely require a surgical intervention. While primary surgical repair seems desirable, it is extremely morbid. Minimally invasive therapies, such as stenting and drainage procedures, have come into greater favor as a result. Any intervention should include establishing enteral access for long-term nutrition.

> *After initial resuscitation, it is critical to avoid further spillage and to try to remove any spillage from the perforation that has already occurred.*

Once the stabilization and source control are established, transfer to a tertiary care facility should be considered. The patients often need to undergo multiple procedures during the initial hospitalization. They will require long-term follow-up with repeat procedures; thus, they are best served in a facility that offers those resources.

F. Conclusion

Esophageal perforation is deadly if it is not quickly recognized and treated. A high index of suspicion based on a patient's history or trauma mechanism is key, and clinicians need to be aware of the nonspecific and sometimes subtle signs of esophageal injury. Once the diagnosis is established, immediate administration of broad antibiotic coverage followed by surgical consult and subsequent control of the perforation are critical. Definitive repair or stabilization can be accomplished either through an open surgical approach or a minimally invasive approach depending on each individual patient's situation.

Key Points

Abdominal Surgical Emergencies: Part 1

- TM should be considered in critically ill patients with classic risk factors such as IBD and *C. difficile* infection, but also in those with multi-system organ failure of unclear etiology.
- Early diagnosis and aggressive treatment are essential. Plain abdominal radiographs should be the first imaging modality and may demonstrate an excessively dilated (frequently right side) colon. Distal obstruction as etiology of colonic dilation needs to be ruled out via contrast enema, abdomen and pelvis CT scan with rectal contrast, or bedside sigmoidoscopy.
- Medical treatment needs to be started immediately for all cases of TM and consists of specific antimicrobial therapy or steroids and immunomodulators for infectious or inflammatory colitides, respectively. However, early surgical consultation and a low threshold for surgical intervention are essential.
- First-line surgical treatment of TM consists of colectomy with end ileostomy, although for select cases of *C. difficile* infection other surgical treatment, such as lavage through a loop ileostomy, are novel strategies.
- Patients with SBO are a heterogenous group and appropriate management ranges from serial examinations and fluid resuscitation to immediate surgical intervention. SBO due to adhesions often responds to nonsurgical management, while patients with hernias most often require surgical management, and those with obstruction due to cancer or volvulus always do.
- In a patient with SBO, regardless of etiology, peritonitis, severe leukocytosis, or lactic acidosis, or imaging findings of pneumatosis and bowel wall thickening are concerning for bowel ischemia or

necrosis and require surgical consultation and most likely intervention.

- Patients with SBO who do not respond to nonsurgical management after 48–72 hours should be considered for surgical intervention.
- Peritonitis is defined as inflammation of the peritoneum and can be classified as primary, secondary, and tertiary.
- Secondary peritonitis is the most common type of peritonitis.
- Treatment for peritonitis includes prompt administration of crystalloids, source control, and antimicrobial therapy.
- Patients presenting with the severe forms of gallbladder and pancreas-related disease such as cholangitis or necrotizing pancreatitis, respectively, are at risk for distributive and/or hypovolemic shock, septic, and sometimes hemorrhagic shock.
- Esophageal perforation often presents with nonspecific symptoms such as chest pain, dysphagia, dyspnea, subcutaneous emphysema, epigastric pain, fever, tachycardia, and tachypnea.

Suggested Readings

1. Aquina CT, Becerra AZ, Probst CP, et al. Patients With Adhesive Small Bowel Obstruction Should Be Primarily Managed by a Surgical Team. *Ann Surg*. 2016;264(3):437-447.
2. Asensio JA, Chahwan S, Forno W, et al. Penetrating esophageal injuries: multicenter study of the American Association for the Surgery of Trauma. *J Trauma*. 2001;50(2):289.
3. Barie PS, Eachempati SR. Acute acalculous cholecystitis. *Gastro Clinics N Am*. 2010;39(2):343-357.
4. Biffl WL, Moore EE, Feliciano DV, et al. Western Trauma Association Critical Decisions in Trauma: Diagnosis and

management of esophageal injuries. *J Trauma Acute Care* Surg. 2015;79(6):1089-1095.

5. Cherry-Bukowiec JR, Miller BS, Doherty GM, et al. Nontrauma emergency surgery: optimal case mix for general surgery and acute care surgery training. *J Trauma*. 2011;71(5):1422-1426.
6. Davis CA, Landercasper J, Gundersen LH, et al. Effective Use of Percutaneous Cholecystostomy in High-Risk Surgical Patients Techniques, Tube Management, and Results. *Arch Surg*. 1999;134(7):727-732.
7. Ferrada P, Patel MB, Poylin V, et al. Surgery or stenting for colonic obstruction: a practice management guideline from the Eastern Association for the Surgery of Trauma. *J Trauma Acute Care Surg*. 2016;80(4):659-664.
8. Ferrada P, Velopulos CG, Sultan S, et al. Timing and type of surgical treatment of *Clostridium difficile*-associated disease: a practice management guideline from the Eastern Association for the Surgery of Trauma. *J Trauma Acute Care Surg*. 2014;76(6):1484-1493.
9. Hawser SP, Bouchillon SK, Hoban DJ, Badal RE: In vitro susceptibilities of aerobic and facultative anaerobic Gram-negative bacilli from patients with intra-abdominal infections worldwide from 2005-2007: Results from the SMART study. *Int J Antimicrob Agents*. 2009;34(6):585-588. 10.1016/j.ijantimicag.2009.07.013.
10. Horwitz B, Krevsky B, Buckman RF Jr, et al. Endoscopic evaluation of penetrating esophageal injuries. *Am J Gastroenterol*. 1993;88:1249-1253.
11. Huffman JL, Schwenker S. Acute acalculous cholecystitis: a review. *Clin Gastroenterol Hepatol*. 2010;8:15-22.
12. Kimura Y, Tadaka T, Strasburg SM, et al. TG13 current terminology, etiology, and epidemiology of acute cholangitis and cholecystitis. *J Hepatobiliary Pancreat Sci*. 2013;20(1):8-23.

13. Kiriyams S, Takada T, Strasberg SM, et al. New diagnostic criteria and severity assessment of acute cholangitis in revised Tokyo Guidelines. *J Hepatobiliary Pancreat Sci*. 2012;19(5):548-556.

14. Ross H, Steele SR, Varma M, et al. Practice parameters for the surgical treatment of ulcerative colitis. *Dis Colon Rectum*. 2014;57(1):5-22.

15. Sailhamer EA, Carson K, Chang Y, et al. Fulminant *Clostridium difficile* colitis: patterns of care and predictors of mortality. *Arch Surg*. 2009;144(5):433-439; discussion 9-40.

16. Sartelli M, Malangoni MA, Abu-Zidan FM, et al. WSES guidelines for management of *Clostridium difficile* infection in surgical patients. *World J Emerg Surg*. 2015;10:38.

17. Sartelli M, Viale P, Catena F, et al. 2013 WSES guidelines for management of intraabdominal infections. *World J Emerg Surg*. 2013;8(1):3. doi:10.1186/1749-7922-8-3.

18. Scotte M, Mauvais F, Bubenheim M, et al. Use of water-soluble contrast medium (gastrografin) does not decrease the need for operative intervention nor the duration of hospital stay in uncomplicated acute adhesive small bowel obstruction? A multicenter, randomized, clinical trial (Adhesive Small Bowel Obstruction Study) and systematic review. *Surgery*. 2017;161(5):1315-1325.

19. Søreide JA, Viste A. Esophageal perforation: diagnostic work-up and clinical decision-making in the first 24 hours. *Scand J Trauma Resusc Emerg Med*. 2011;19:66. doi:10.1186/1757-7241-19-66.

20. Strong S, Steele SR, Boutrous M, et al. Clinical Practice Guideline for the Surgical Management of Crohn's Disease. *Dis Colon Rectum*. 2015;58(11):1021-1036.

21. Vial CM, Whyte RI. Boerhaave's syndrome: diagnosis and treatment. *Surg Clin North Am*. 2005;85:515-524. doi: 10.1016/j.suc.2005.01.010. ix.

Suggested Websites

1. http://www.aasld.org/practiceguidelines/Documents/ascitesupdate2013.pdf
2. C-diff - https://www.east.org/education/practice-management-guidelines/*clostridium-difficile*-associated-disease---timing-and-type-of-surgical-treatment
3. SBO - https://www.east.org/education/practice-management-guidelines/smallbowelobstruction-evaluation-and-management-of
4. Cholecystitis https://www.east.org/education/publications/landmark-papers-in-trauma-and-acute-care-surgery/emergency-general-surgery/cholecystitis

Chapter 14

ABDOMINAL SURGICAL EMERGENCIES: PART 2

✓ Objectives

- Classify and predict severity of acute pancreatitis.
- Recognize complications associated with acute pancreatitis.
- Outline appropriate management of acute pancreatitis.
- Outline the diagnostic methods for determining location and type of severe gastrointestinal hemorrhage.
- Review the general management principles of severe upper and lower gastrointestinal hemorrhage.
- Identify the diagnosis and management of intra-abdominal hypertension and abdominal compartment syndrome.

Case Study

A 58-year-old man with cirrhosis secondary to chronic alcohol abuse arrives in the emergency department reporting upper abdominal pain and generalized weakness for the past 2 days. He is currently intoxicated and is unable to provide a detailed history. His vital signs reveal a temperature of 37.5°C (99.5°F), respiratory rate of 28 breaths/min, blood pressure of 92/70 mm Hg, and a heart rate of 115 beats/min. On physical examination, his abdomen is rotund and tender to palpation in the mid-epigastrium. As an intravenous crystalloid fluid infusion is started, the patient becomes more lethargic.

- What is the differential diagnosis based on the patient's risk factors and clinical findings?
- What diagnostic studies would be indicated?
- What would your initial management consist of?

I. INTRODUCTION

The conditions covered in this chapter highlight the need for closely coordinated, multidisciplinary and multi specialty care of the seriously ill. Severe pancreatitis, gastrointestinal (GI) hemorrhage, and abdominal compartment syndrome require initial and continuing communication among the primary provider team and various consultants. Expedient discussion, planning and implementation of resuscitation and interventions often requires a lead service to strategize the patient's care and organize alternative treatment if initial therapy failed.

II. PANCREATITIS

A. Diagnosis and Classification

Pancreatitis is the most common GI condition requiring hospitalization in the United States and United Kingdom. A worldwide increase in the incidence of pancreatitis is most likely associated with the concurrent increase in obesity and gallstones. Pancreatitis is defined by having two of the three following criteria:

1. Symptoms consistent with pancreatitis (eg, epigastric pain)
2. Serum amylase and/or lipase greater than three times the upper limit of normal

3. Cross-sectional imaging or transabdominal ultrasonography revealing pancreatitis

The two most frequent causes of acute pancreatitis include gallstones and alcohol. Other causes are:

- Hypertriglyceridemia
- Hypercalcemia
- Endoscopic retrograde cholangiopancreatography
- Trauma
- Associated conditions (diabetes mellitus, obesity, smoking)
- Genetic causes
- Autoimmune disorders
- Medications(furosemide, steroids)
- Infection (mumps)
- Post-cardiopulmonary bypass
- Obstruction of pancreatic duct
- Idiopathic

There are two types of acute pancreatitis: interstitial edematous pancreatitis and necrotizing pancreatitis. Although most patients admitted with pancreatitis will have the interstitial edematous type characterized with a mild disease course and a mortality rate around 2%, about 20% of patients will develop necrotizing pancreatitis associated with local and systemic complications and a mortality rate that exceeds 30% in the most severe bouts.

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Twenty percent of patients with pancreatitis will develop necrotizing pancreatitis that can have a mortality rate upwards of 30%.

Methods to classify the severity of acute pancreatitis include the Revised Atlanta Classification (RAC) and the Determinant-Based Classification (DBC) as shown below.

> *Severity of pancreatitis is based on an associated level of organ dysfunction or failure.*

The RAC sought to clarify terminology used in the original Atlanta Classification to differentiate the two types of acute pancreatitis, interstitial edematous pancreatitis and necrotizing pancreatitis, and describe fluid collections which are viewed as local complications of acute pancreatitis. These fluid collections are defined as acute peripancreatic fluid collection (APFC), acute necrotic collection (ANC) (sterile or infected), pancreatic pseudocyst (PP), and walled-off necrosis (WON) (sterile or infected) (**Table 14-1**).

Revised Atlanta Classification (RAC) (2012)

Mild acute pancreatitis

- No organ failure
- No local or systemic complications

Moderately severe acute pancreatitis

- Transient (< 48 hours) organ failure and/or
- Local or systemic complications without persistent organ failure

Severe acute pancreatitis

- Persistent organ failure (> 48 hours), single or multiorgan

Data from Banks PA, et al. *Gut*. 2013;62:102-111.

Determinant-Based Classification (DBC)

Mild acute pancreatitis

- No organ failure
- No (peri)pancreatic necrosis

Moderate acute pancreatitis

- Sterile (peri)pancreatic necrosis *and/or* transient organ failure

Severe acute pancreatitis

- Infected (peri)pancreatic necrosis *or* persistent organ failure

Critical acute pancreatitis

- Infected (peri)pancreatic necrosis *and* persistent organ failure

Data from Talukdar R and Vege R. Acute pancreatitis. *Curr Opin Gastroenterol*. 2015;31:376.

Table 14-1 Definition of Pancreatic and Peripancreatic Collections

Interstitial Edematous Pancreatitis	Necrotizing Pancreatitis
Acute peripancreatic fluid collection • Peripancreatic fluid associated with interstitial edematous pancreatitis • Seen within the first 4 weeks after onset • Homogenous collection with fluid density • No definable wall encapsulating the fluid	Acute necrotic collection • Variable amounts of both fluid and necrosis • Can involve the pancreas and peripancreatic tissue • Heterogenous density • No definable wall
Pancreatic pseudocyst • Well-circumscribed collection with fluid density • Homogenous • No non-liquid component • Takes at least 4 weeks to develop after onset of acute interstitial edematous pancreatitis	Walled-off necrosis • Encapsulated collection of pancreatic and/or peripancreatic necrosis • Heterogenous with liquid and non-liquid density • Usually requires 4 weeks after onset of acute necrotizing pancreatitis

Reproduced from Gut. Banks PA, et al. 62, 102-111, 2013, with permission from BMJ Publishing Group Ltd.

The morphologic characteristics of acute pancreatitis are best seen on contrast-enhanced computed tomography (CECT). The fluid collections that may result from interstitial edematous pancreatitis (**Figure 14-1**) are APFC and PP; ANC and WON develop from necrotizing pancreatitis. On CECT, the pancreas in interstitial edematous pancreatitis is enlarged secondary to edema, has relatively homogenous enhancement, and the peripancreatic fat shows inflammatory changes. There may be the development of an APFC which occurs during the first 4 weeks after the onset of interstitial edematous pancreatitis. An APFC appears on CECT as a homogenous collection with fluid density confined by the fascial planes surrounding the pancreas. After at least 4 weeks, this collection of fluid may develop a mature, well-circumscribed inflammatory wall at which time it is referred to as a PP (**Figure 14-2**).

Figure 14-1. Interstitial Edema Pancreatitis

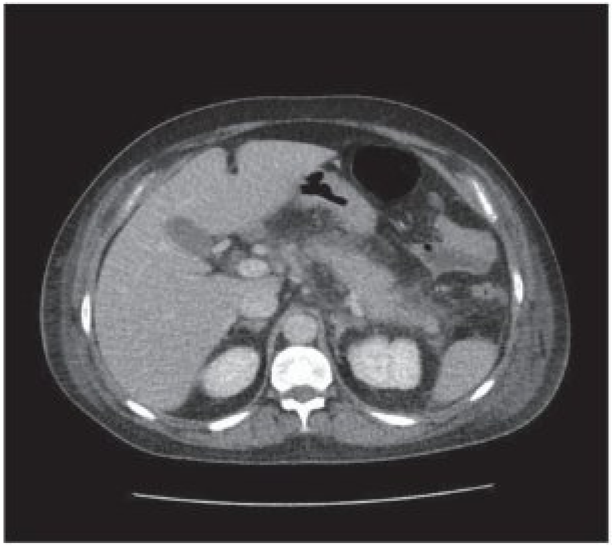

Image courtesy of Daniel Wu, DO.

Figure 14-2. Pancreatic Pseudocyst (starred area)

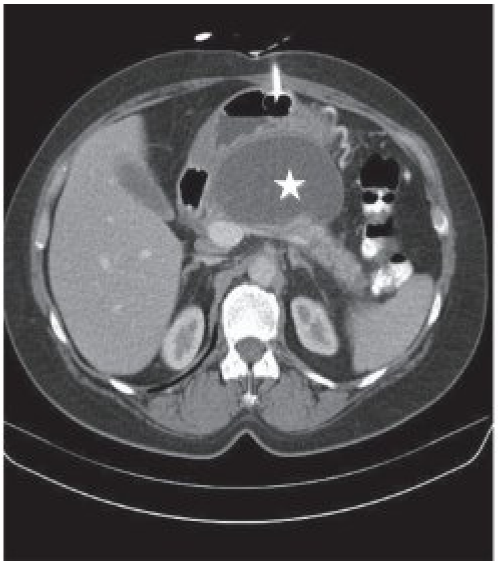

Image courtesy of Daniel Wu, DO.

Necrotizing pancreatitis is defined as necrosis of the pancreatic parenchyma, the peripancreatic tissue, or both. Necrosis is evident on CECT as poorly enhanced pancreatic parenchyma and surrounding tissue. This impairment of perfusion evolves over several days which explains why an early CECT may underestimate the eventual amount of pancreatic and peripancreatic necrosis. An ANC occurs only in the setting of necrotizing pancreatitis and is characterized as a heterogenous collection of solid and liquid densities without a definable wall. After 4 weeks, encapsulation of the necrotic tissue may form and is termed WON. Both ANC and WON may be sterile or infected (**Figures 14-3** and **14-4**).

Figure 14-3. Pancreatic Necrosis without Fluid Collections (circled area necrosis-no contrast)

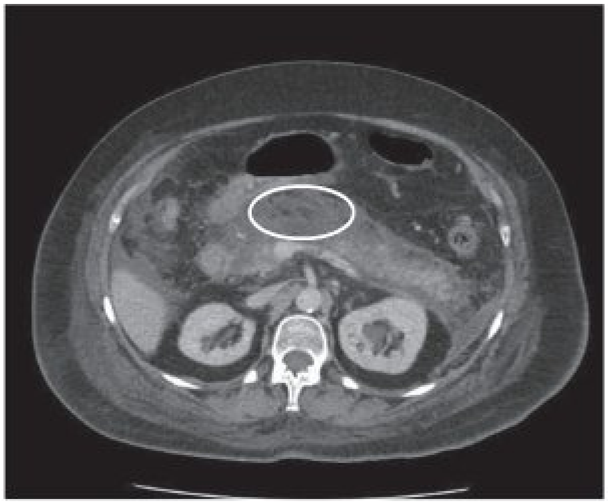

Image courtesy of Daniel Wu, DO.

Figure 14-4. Pancreatic Necrosis with Peripancreatic Fluid Collections (starred areas)

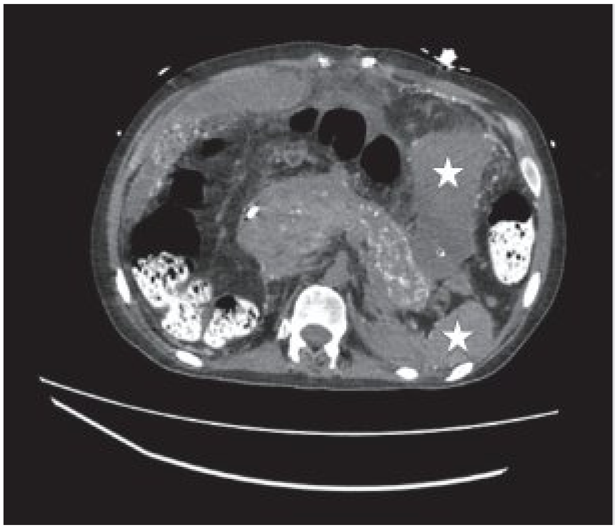

Image courtesy of Mary Jane Reed, MD.

Suspicion for the presence of local complications, which include gastric outlet obstruction, splenic and portal vein thrombosis, and colonic necrosis, is heightened because of persistent or recurrent abdominal pain, worsened organ function, and clinical signs of sepsis including fever and leukocytosis. These local complications can be confirmed on CECT. Systemic complications confer greater severity of illness in acute pancreatitis. According to the RAC, the organ systems that should be assessed for organ failure are respiratory, cardiovascular, and renal. Persistent organ failure (> 48 hours) is the defining feature of severe acute pancreatitis. Exacerbation of comorbid illnesses such as coronary artery disease, chronic obstructive pulmonary disease, or diabetes mellitus is also considered a systemic complication.

The ability to predict which patients will develop severe acute pancreatitis is useful in that this allows appropriate triage to the proper level of monitoring (intermediate or intensive care unit [ICU]) and early initiation of appropriate therapy. Multiple scoring systems, combining clinical and laboratory parameters, are available to predict the severity of acute pancreatitis. These include Ranson score, Acute Physiology and Chronic Health Evaluation II (APACHE II), Bedside Index for Severity in Acute Pancreatitis, Glasgow Imrie, and Systemic Inflammatory Response Syndrome (SIRS) criteria. Unfortunately, most of these scoring systems have a low-positive predictive value and, therefore, no consistently reliable system for severity prediction exists. However, signs of persistent SIRS (> 48 hours) increase the risk of organ failure associated with acute pancreatitis and portend a poor prognosis. Other predictors of severity in acute pancreatitis include elevated C-reactive protein level and indicators of intravascular depletion as a result of third-space fluid losses such as hemoconcentration and azotemia.

B. Management

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> *Tailor fluid therapy based on intravascular depletion and risk of cardiopulmonary overload.*
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> !

Management consists of optimal fluid resuscitation with the goal to provide enough intravascular volume to maintain pancreatic perfusion. Fluid therapy needs to be tailored to the degree of intravascular volume depletion and the cardiopulmonary reserve that is available to handle the fluid because volume overload is a major risk of fluid resuscitation. Maintaining hemodynamic stability and targeting a urine output of at least 0.5 mL/kg/h aids in preventing acute kidney injury. Lactated Ringer solution is preferred by some clinicians over normal saline in reducing inflammatory markers although further studies need to be done.

The enteral route for provision of nutrition is preferred in patients with acute pancreatitis. Early enteral nutrition helps to maintain gut mucosal barrier integrity, decreases pathogenic intestinal flora, and reduces infection and mortality compared with parenteral nutrition. No evidence exists to suggest the superiority of elemental or semi-elemental formulas compared with polymeric formulas. Post-pyloric feeding has not been shown to be superior to gastric enteral feeding in acute pancreatitis. Delay in gastric emptying, reflux, gastric feeding intolerance, and increased risk of aspiration would be indications to pursue the post-pyloric route.

Total parenteral nutrition (TPN) is more expensive and is associated with increased infectious complications, organ failure, and mortality than enteral nutrition in patients with severe acute pancreatitis. TPN should be used in those situations when enteral feeding is not tolerated or does not provide adequate nutrition to meet caloric needs.

Most APFCs remain sterile, typically resolve spontaneously, and therefore do not need treatment. A PP may require therapy if patients experience symptoms such as abdominal pain, early satiety, fever, chills, or jaundice. Endoscopic and occasionally percutaneous catheter drainage approaches have supplanted surgical techniques for management.

ANCs and WON are composed of necrotic pancreatic parenchyma and/or peripancreatic tissue. These collections may be sterile or become infected. There is no benefit of providing prophylactic antibiotics in an attempt to prevent secondary infection. In addition, surgical debridement of sterile necrosis has not been proven to be helpful in the absence of obstructive symptoms or failure to thrive.

The distinction between sterile and infected necrosis is imperative because infected pancreatic and peripancreatic necrosis is associated with increased morbidity and mortality. Once infection is confirmed, antibiotics with high inhibitory concentrations within pancreatic tissue (eg, carbapenems, fluoroquinolones, metronidazole) are administered which have been shown to successfully treat infected necrosis in stable patients, obviating the need for other intervention. For patients who fail to improve or show signs of deterioration, a step-up approach with a delay in definitive treatment is standard practice. This step-up approach consists of, in addition to antibiotic administration, percutaneous drainage as needed, and after a delay of several weeks, minimally invasive debridement (eg, percutaneous, endoscopic, laparoscopic, and retroperitoneal approaches), if necessary. This approach is superior to open necrosectomy with respect to the risk of major complications or death. Approximately one-third of patients will not require debridement. Open surgery should be reserved for when less invasive techniques fail.

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The step-up approach to pancreatic and peripancreatic necrosis includes antibiotics, percutaneous drainage, then invasive debridement, if necessary.

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Patients diagnosed with acute pancreatitis should have an evaluation for gallstones with abdominal ultrasonography. In those patients determined to have mild gallstone pancreatitis, cholecystectomy performed during the initial hospital admission prevents recurrent disease. Cholecystectomy may need to be deferred in cases of necrotizing pancreatitis to allow for resolution of the acute inflammatory changes, thereby improving surgical exposure of the gallbladder.

Inflammation as a result of pancreatitis can lead to both thrombotic and hemorrhagic complications. These vascular complications occur in 1–23% of patients with pancreatitis and are associated with considerable morbidity and mortality. Although rarely developing with mild acute pancreatitis, the pancreatic and peripancreatic fluid collections, necrosis, and infection that define more severe bouts of acute pancreatitis contribute to the development of vascular complications.

Venous injuries occur more frequently than arterial injuries. Portal and splenic vein thrombosis happen in 23% and 22% of cases of pancreatitis, respectively. Because splanchnic thrombosis may spontaneously resolve with appropriate management of pancreatitis, treatment with anticoagulation should be instituted when clot burden results in hepatic decompensation or compromise of bowel perfusion.

Pseudoaneurysms are the predominant cause of arterial hemorrhage associated with pancreatitis. Direct trauma to adjacent vessels from radiologically placed drains may also lead to arterial hemorrhage. Because arterial complications are associated with 34–52% mortality, early recognition and treatment are warranted. Symptomatic pseudoaneurysms lead to abdominal pain because of retroperitoneal bleeding. The most common site for pseudoaneurysms is the splenic artery (35–50%), followed by gastroduodenal and pancreaticoduodenal arteries and, less commonly, mesenteric, colic, and hepatic vessels. Identification of a pseudoaneurysm on CECT can be managed with angiographic embolization. The need for surgical management, especially with active hemorrhage and unsuccessful interventional radiology attempts at hemorrhage cessation, remains a viable option.

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> *Pancreatitis recurs in nearly half of occurrences when patient risk factors are not recognized and addressed.*
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> !

Determining the etiology of and providing appropriate management for acute pancreatitis offers an effective strategy to prevent recurrence of the disease. The recurrence rate of acute pancreatitis, which can be as high as 25%, approaches 50% in patients whose risk factors have not been recognized or addressed. After acute pancreatitis, pancreatic exocrine and endocrine insufficiency develop in 20–30% of patients and chronic pancreatitis arises in one-third to one-half of those patients. Risk factors for the transition to recurrent attacks and chronic pancreatitis include the severity of the initial attack, the extent of pancreatic necrosis, and the cause of acute pancreatitis. Long duration heavy alcohol use as the cause and smoking as a cofactor significantly increase the risk of progression to chronic pancreatitis.

III. GASTROINTESTINAL HEMORRHAGE

Mortality from a GI bleed could be high, especially if associated with other risk factors. The most important first step is to obtain hemodynamic stability. Adequate IV access is crucial, whether it be large-bore peripheral or central access, and consider an arterial line for hemodynamic monitoring. Initially, resuscitation will begin with intravenous fluids and may transition to the administration of blood products if the hemodynamic status of the patient does not improve. The goal of massive blood resuscitation (>10 units of packed red blood cells within 24 hours) should be to provide products in the 1:1:1 method (packed cells: plasma: platelets) unless whole blood is available. Vasopressor agents should be used as an adjunct to appropriate volume resuscitation. The American College of Gastroenterology (ACG) recommends maintaining a hemoglobin level of 7 g/dL in patients with massive bleeding, 9 g/dL in those with comorbid illness, especially cardiac ischemia, or a predicted delay to intervention. This low threshold reduced the amount of blood product transfused and incidence of rebleeding while improving survival.

Once intravenous resuscitation has begun, blood tests should be drawn and are recommended to be drawn serially. Hemoglobin and hematocrit, coagulation studies (including prothrombin time [PT], partial thromboplastin time [PTT], international normalized ratio [INR], and fibrinogen), a basic metabolic panel, and type and crossmatch should be obtained. Thromboelastography, which is a method to test for the efficiency of blood coagulation, is being used more frequently in ICUs and is used to guide resuscitation.

A complete history should be obtained from the patient or a spokesperson for the patient. Special note should be taken to inquire about events leading up to the hospitalization as well as any known history of liver disease, previous GI bleeds, surgeries, or other GI disorders. Use of nonsteroidal anti-inflammatory agents, antiplatelet agents, or anticoagulants should also be discussed.

Reversal of anticoagulants is imperative in the actively bleeding patient. The process by which to achieve this is becoming increasingly difficult with the ever-expanding types of anticoagulants available. For patients receiving coumadin therapy, the INR should be reversed to 1.5 or less. This has proven to decrease the risk of rebleeding. Any INR > 1.5 is an independent predictor of mortality.

> *Standard laboratory testing is not accurate for direct-acting oral anticoagulants. Reversal agents are more readily available.*

Many new anticoagulants have been introduced and will likely continue to be developed. These agents have brought about new considerations in GI hemorrhage. Standard laboratory testing performed to evaluate coagulation is not accurate for these medications. INR, activated partial thromboplastin time (aPTT), and PT may variably be elevated but the level of elevation does not correspond to the level of active medication in the bloodstream. Thromboelastography is helpful in evaluating the degree of medication effect. Reversal of these direct-acting oral anticoagulants (DOACs) was not initially available when these products were approved for use. Reversal agents have been developed and are becoming more readily available. For the type of anticoagulant and its reversal refer to **Table 14-2**.

Table 14-2 Anticoagulants and Their Properties

			Reversal Agent(s) and Antidotes			
Drug	**MOA**	**Half Life**	**Agent**	**Dose**	**Max Dose**	**Peak Effect**
Dabigatran etexilate	Direct thrombin inhibitor	14–17 hours Mild-moderate kidney impairment: 15–18 hours Severe kidney impairment: 28 hours	Idarucizumab, (4F-PCC if Idarucizumab unavailable) Can consider oral charcoal if ingestion < 2–4 hours	5 grams in two divided doses 15 minutes apart	5 grams *	Time of infusion to hours
Apixaban	Factor Xa inhibitor	8–15 hours	Andexanet alfa or 4F-PCC Can consider oral charcoal if ingestion < 6 hours	Andexanet alfa dose for 5 mg or less apixaban dose taken < 8 hours OR any dose of apixaban taken > 8 hours give Andexanet alfa 400 mg IV bolus then 4 mg/min infusion x 2 hours* For apixaban dose > 5 mg or dose unknown taken < 8 hours give Andexanet alfa dose 800 mg IV bolus then 8 mg/min x 2 hours* 4F-PCC 25–50 u/kg		
Rivaroxaban	Factor Xa inhibitor	5–9 hours Geriatrics 11–13 hours	Andexanet alfa or 4F-PCC Can consider oral charcoal if ingestion < 8 hours	Andexanet alfa dose for 10 mg or less rivaroxaban dose taken < 8 hours OR any dose of rivaroxaban taken > 8 hours give Andexanet alfa 400 mg IV bolus then 4 mg/min infusion x 2 hours* For rivaroxaban dose > 10 mg or dose unknown taken < 8 hours give Andexanet alfa dose 800 mg IV bolus then 8 mg/min x 2 hours*		
Edoxaban tosylate	Factor Xa inhibitor	10–14 hours	4F-PCC, Can consider oral charcoal if ingestion < 2–4 hours	4F-PCC 25–50 u/kg * for possible off-label use of Andexanet alpha		
Fondaparinux	Factor Xa inhibitor	17–21 hours	4F-PCC (Recombinant Factor VIIa)*	4F-PCC 25–50 u/kg	5000 units	30 minutes

Warfarin	Vitamin K antagonist	20–60 hours	4F-PCC administered	**INR 4F-PCC**		
				2–4 25 u/kg	2500 units	30 minutes
				4–6 35 u/kg	3500 units	
			+	> 6 50 u/kg	5000 units	
			Vitamin K	Vitamin K		Vitamin K onset
			OR	5–10 mg IV		2 hours, 12–14 hours
			Vitamin K	q12 hours prn		for IV full effect
			+			
			FFP	FFP 10–15 mL/kg		FFP 1–4 hours

Abbreviations: FFP, fresh frozen plasma; MOA, mechanism of action; 4F-PCC, 4-Factor prothrombin complex concentrate; u/kg, units per kilogram; * suggest Pharmacy consultation

The first key in diagnosis of GI hemorrhage is differentiation of upper GI hemorrhage from lower. The ACG divides GI bleeding into three distinct categories:

1. Upper GI bleeding originating proximal to the ligament of Treitz
2. Middle GI bleeding from the small intestine
3. Lower GI bleeding from the colon or rectum

For the purposes of this chapter, the traditional definition utilizing the ligament of Treitz as the division between the upper and lower GI tract will be used as reference. We will be discussing upper GI bleeding and lower GI bleeding separately.

A. Upper Gastrointestinal Bleeding (UGIB)

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The traditional division between upper gastrointestinal bleeding and lower is the ligament of Treitz.

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Upper GI bleeding can be mild to immediately life-threatening. Blood loss originates proximal to the ligament of Treitz and can involve the esophagus, stomach, and/or the duodenum. Treatment of *Helicobacter pylori* infection and the use of acid-suppressive therapy for peptic ulcer disease (PUD) has led to a decline in the incidence of UGIB to 100 cases per 100,000 population per year. Despite improved management, morbidity and mortality from GI bleeding have remained relatively stable at 6% to 10%. The aging population presenting with an increasing number of comorbidities and the use of newer anticoagulant medications are at increased risk of bleeding. Approximately 80% of mortality in patients with GI bleeding is attributed to the exacerbation of other illnesses. Patients with GI bleed require close monitoring and management in an ICU.

1. Diagnosis and Presentation

A team approach that involves an intensivist, gastroenterologist, radiologist, and surgeon are needed to most effectively treat the patient with rapid assessment, diagnosis, and intervention. A careful history and physical examination should provide information to identify the cause and source of the bleeding and discover any complicating conditions or medications. Questioning should reveal timing, duration, volume, and severity of bleeding. UGIB can have findings of coffee ground emesis, hematemesis, melena, or even hematochezia if bleeding is rapid. A medical history of previous UGIB, abdominal pain, change in bowel habits, the presence of PUD, alcohol consumption, vomiting or retching, stigmata of cirrhosis, hepatitis, liver disease, coagulation disorders, inflammatory bowel disease, weight loss, anorexia, or malignancy should be obtained. Inquiry about surgical history, including gastrectomy and abdominal aortic aneurysm repair, is also important. Medications should be reviewed for the use of nonsteroidal anti-inflammatory drugs (NSAIDs), aspirin, anticoagulants, and antiplatelet agents. A family history of coagulation disorders or a history of recurrent bleeding should be discussed.

Assessment of vital signs may indicate hypovolemia, including tachycardia and orthostatic hypotension. Abdominal and rectal examination with guaiac testing should be performed. Laboratory tests should include a complete blood count, coagulation studies, type and cross match, creatinine level, blood urea nitrogen level, and liver enzymes.

The placement of a nasogastric tube in patients presenting with GI bleeding is a common practice that remains controversial. The benefits of nasogastric lavage include confirmation of an upper GI source of bleeding, better visualization during endoscopy, and prediction of high-risk lesions based on the severity of the bleeding. The return of bilious material without any blood makes a distal source more likely.

Non-variceal upper GI bleeding (NVUGIB) must be differentiated from variceal upper GI bleeding (VUGIB). The differential diagnosis diverges based on the type of bleeding.

Diagnostic tools for the evaluation of UGIB include endoscopy and angiography. These tests are aimed at detecting the location, source, and activity of bleeding. Other tests may be necessary in specific clinical situations, such as computed tomography (CT) scanning when abdominal pain is a prominent symptom to rule out ischemia, infarction, and perforation. Endoscopy and to some extent angiography have the advantage of allowing both diagnosis and therapy.

NVUGIB

Causes of NVUGIB include peptic ulcer disease (duodenal and gastric ulcers), Mallory-Weiss tear, stress gastritis, Dieulafoy lesion, angiodysplasia, benign or malignant neoplasms, hemobilia, and aortoduodenal fistula. These sources account for 80–90% of upper GI bleeding.

a. Peptic Ulcer Disease

Peptic ulcer disease (PUD) is the most common cause of NVUGIB, approximately 40% of all cases. NSAID use and *Helicobacter pylori* infection are the common causes of PUD. Bleeding develops as a consequence of peptic acid erosion of the mucosal surface. Significant bleeding results when there is involvement of an artery of the submucosa or with penetration of the ulcer into an even larger vessel (gastroduodenal artery, pancreaticoduodenal artery, or left gastric artery).

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Peptic ulcer disease is the most common source of non-variceal upper gastrointestinal bleeding. This can commonly be caused by NSAID use or H. pylori infection.

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b. Mallory-Weiss Tears

Mallory-Weiss tears are mucosal and submucosal tears that occur near the gastroesophageal junction from sudden increases in pressure within the cardia and lower esophagus. They develop after a period of intense retching and vomiting commonly following binge drinking in alcoholic patients but can occur in any patient who has a history of repeated emesis. They account for 5% to 15% of cases of upper GI bleeding. Ninety percent of bleeding episodes are self-limited and the mucosa often heals within 72 hours.

c. Stress-Related Gastritis

Stress-related gastritis is characterized by the appearance of multiple superficial erosions of the entire stomach, most commonly in the body. The entity is thought to result from the combination of acid and pepsin injury in the context of ischemia from hypoperfusion states. Ventilator dependence for longer than 48 hours and coagulopathy are risk factors for increased bleeding from stress gastritis. Two patient populations in which this can be seen are patients with increased intracranial pressure (Cushing ulcer) and major burns (Curling ulcer).

d. Dieulafoy Lesions

Dieulafoy lesions are vascular malformations found primarily along the lesser curve of the stomach within 6 cm of the gastroesophageal junction. They are the result of the rupture of unusually large visible vessels (1 to 3 mm) found in the gastric submucosa. Erosion of the gastric mucosa overlying these vessels leads to bleeding. The mucosal defect is usually small (2 to 5 mm) and may be difficult to identify because of normal surrounding mucosa. They account for less than 5% of cases of upper GI bleeding.

e. Angiodysplasia

Angiodysplasia (arteriovenous malformation or vascular ectasia) is another source of upper GI bleeding and accounts for approximately 5% to 10% of cases.

f. Neoplasms

Benign or malignant neoplasms are usually associated with chronic anemia or hemoccultpositive stool. They can also present as ulcerative lesions seen with gastrointestinal stromal tumor, lipomas, leiomyomas, and lymphomas. They account for less than 5% of cases of upper GI bleeding.

g. Hemobilia

Hemobilia is associated with trauma, liver biopsy, recent instrumentation of the biliary tree (endoscopic retrograde cholangiopancreatography [ERCP]), and biliary or hepatic neoplasms. Suspect the diagnosis in patients who present with bleeding, right upper quadrant pain, and jaundice.

h. Aortoenteric Fistula

Aortoenteric fistula typically develops in a patient with previous repair of an abdominal aortic aneurysm but could occur with an inflammatory or infectious aortitis, and it may develop in up to 1% of aortic graft cases. It can also occur days to years after surgery, with 3 years being the median interval. Fistulas are located in the third portion of the duodenum. Patients will usually have a small bleed (herald bleed) that occurs before the major bleeding that is often massive and fatal unless immediate intervention is undertaken.

VUGIB

Have a high index of suspicion for hemobilia in patients who present with bleeding, right upper quadrant pain, and jaundice.

VUGIB is a serious complication of portal hypertension, most often in the setting of cirrhosis. In patients with cirrhosis, 25% to 50% of patients have varices. One-third of patients with varices will develop a variceal bleed. The dilated submucosal veins develop in response to the portal hypertension, providing a collateral pathway for decompression of the portal system into the systemic venous circulation. Varices are most common in the distal esophagus and can reach sizes of 1 to 2 cm. As they enlarge, the overlying mucosa becomes increasingly tenuous, excoriating with minimal trauma. Varices are most commonly seen in the esophagus but may also develop in the stomach and hemorrhoidal plexus of the rectum. The likelihood of developing a bleed increases with the size of the varices and worsening portal hypertension. Bleeding is frequently massive, accompanied by hematemesis and hemodynamic instability. Mortality secondary to variceal hemorrhage is approximately 20–30%.

2. Treatment

Therapeutic options range from pharmacologic, endoscopic, angiographic, to surgical. They are often complementary and require a multidisciplinary team approach.

a. Proton Pump Inhibitors

The introduction of proton pump inhibitors (PPIs) and the progress made in endoscopic technology have revolutionized the management of GI bleeding. Acid suppression has been shown to play a role in the inactivation of pepsin, optimization of platelet function, and inhibition of fibrinolysis. Subsequently, clot stabilization and ulcer healing may be more effective and rapid within a less acidic environment. Infusions of PPIs are used when NVUGIB is suspected. Effective acid suppression reduces the rate of bleeding recurrence, use of surgery, and mortality. An intravenous bolus followed by a twice-daily PPI is recommended prior to endoscopy and has been shown to reduce the need for therapeutic endoscopic interventions. If high-risk stigmata are seen during endoscopic therapy, a continuous infusion of a PPI is recommended for 24–72 hours.

b. Vasoconstrictors

> *Prophylactic use of second- or third generation cephalosporins should be considered in patients with variceal hemorrhage because of the risk of spontaneous bacterial peritonitis.*

The goal of pharmacologic therapy in VUGIB is to reduce portal venous blood flow and thus pressure. Useful medications include vasopressin, terlipressin, octreotide, and somatostatin. These agents are successful in controlling variceal hemorrhage in up to 80% of cases. Vasopressin promotes splanchnic arteriolar constriction, leading to decreased portal venous pressure along with systemic vasoconstriction. Vasopressin may cause coronary artery vasospasm, angina, or hypertension. Administration of nitroglycerin along with vasopressin may prevent the deleterious effects on the coronary circulation. Somatostatin and its longer acting analog, octreotide, inhibit the release of vasodilator hormones and indirectly cause splanchnic vasoconstriction without affecting the systemic circulation and thus results in a decrease in portal pressure. They are the agents of choice because of their adverse effect profile. Somatostatin is administered as a 250-μg IV bolus followed by an infusion of 250 μg/h for up to 5 days to prevent rebleeding. Octreotide has a longer half-life than somatostatin and is administered as a 25- to 100-μg IV bolus followed by infusion at 25–100 μg/h. Continuous IV infusion of these agents results in temporary control of bleeding and allows time for resuscitation and appropriate diagnostic and therapeutic interventions. Vasoactive medications have been shown to decrease mortality, decrease hospital stay, improve hemostasis, and decrease blood transfusion requirements.

c. Antibiotics

Prophylactic antibiotics should be started early in patients with variceal hemorrhage because they have a risk of developing spontaneous bacterial peritonitis. Second-or third-generation cephalosporins have been used with good success. The use of prophylactic antibiotics in patients with variceal bleeding has been shown to decrease their mortality rate.

d. Endoscopy

> *Endoscopy has become the preferred diagnostic and therapeutic modality for upper gastrointestinal bleeding with diagnosis achieved in 95% of patients.*

Endoscopy has become the preferred diagnostic and therapeutic modality for upper GI bleeding because of its accuracy and low complication rate. Specific diagnosis can be achieved in 95% of patients. The optimal timing of endoscopy remains a balance between clinical need and resources. Endoscopy should ideally be performed when the patient is clinically stabilized and able to tolerate the procedure. It is recommended that upper endoscopy be performed within 24 hours in patients with suspected NVUGIB. If endoscopy is not quickly available, consider transfer to a facility with endoscopic capabilities.

Endoscopy can identify stigmata of a recent bleed known to correlate well with an increased risk for rebleeding and thus a need for endoscopic therapy. In patients undergoing upper GI endoscopy, 20% to 35% will require a therapeutic endoscopic intervention. Different forms of endoscopic therapy include injection technique, thermal technique, and mechanical technique. In many cases, a combination of these modalities is used to treat a single bleeding lesion or one at high risk of bleeding. Endoscopy is successful at stopping acute bleeding in 90% of cases. Rebleeding occurs in about 20% of patients and increases the risk of mortality. With rebleeding, repeated endoscopy is typically justified.

In patients with VUGIB, endoscopic sclerotherapy and endoscopic band ligation are the mainstays of therapy. These procedures are successful in achieving hemostasis in 80% to 90% of patients. Despite its high effectiveness in controlling bleeding, the complication rate with sclerotherapy can be as high as 40%. Band ligation has a lower rate of complications, but it can be difficult to perform during acute bleeding. Even when bleeding is short lived, endoscopy should be pursued because the rate of significant rebleeding is high.

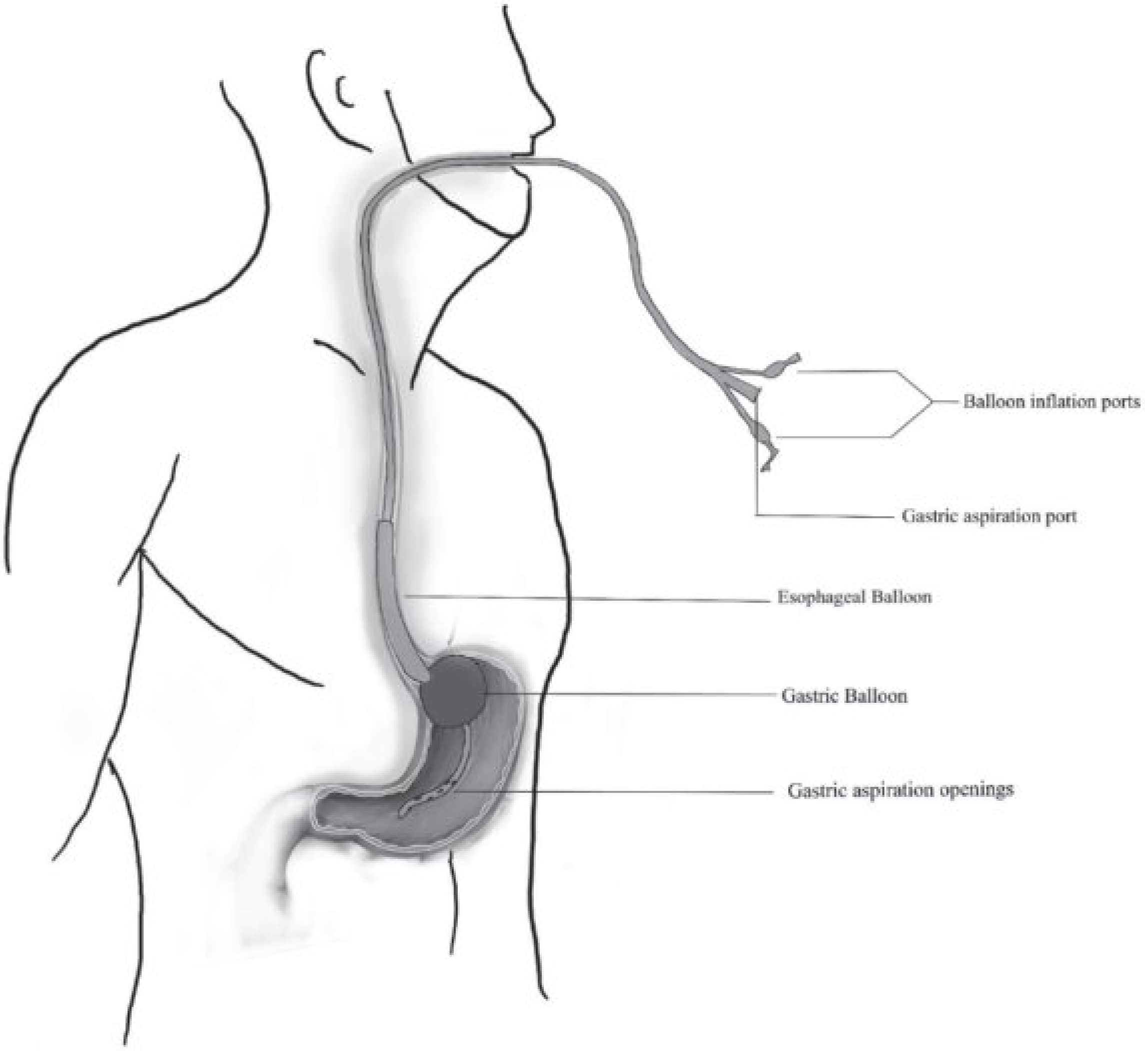
e. Angiography with Embolization

When endoscopy fails to control bleeding, angiography with embolization is now considered the second-line treatment before proceeding with surgical intervention in the 5–10% of patients who are unresponsive to pharmacologic or endoscopic treatment. Embolization has a 90% success rate and is less invasive than surgical intervention. Prior endoscopic tattooing can facilitate the procedure. Super-selective embolization is preferred because it carries a lower complication rate than embolization of larger vessels.

f. Balloon Tamponade

In patients for whom pharmacologic or endoscopic therapy fails to control variceal hemorrhage, balloon tamponade can be used to temporize the bleeding for 24 hours. A high risk of rebleeding exists after deflation of the balloon, in addition to the risk of esophageal rupture; therefore, a more definitive therapy should be undertaken (**Figure 14-5**).

Figure 14-5. Diagram of Variceal Balloon Tamponade Device


Balloon inflation ports
Gastric aspiration port
Esophageal Balloon
Gastric Balloon
Gastric aspiration openings

g. Surgery

Surgical intervention is usually reserved for cases in which endoscopy and angiography with embolization have failed to control the bleeding due to PUD. Patients requiring surgery are typically critically ill and have higher rates of mortality. Indications for surgery were traditionally based on the blood transfusion requirements. Although not absolute, many surgical consultants consider an ongoing blood transfusion requirement in excess of 6 U is an indication for surgical consultation and possible intervention in older patients, and 8 to10 U for younger patients. Hemodynamic instability despite significant resuscitation (> 6 U transfusion), recurrent hemorrhage after initial stabilization (with up to two attempts at obtaining endoscopic hemostasis), continued slow bleeding with a transfusion requirement greater than 3 U/day may all prompt evaluation and consideration for surgery. If surgery is required, the procedure of choice depends on the underlying pathophysiology.

h. Transjugular Intrahepatic Portosystemic Shunt (TIPS)

Emergent portal decompression with a TIPS should be considered in patients with refractory variceal bleeding despite medical management. The TIPS procedure involves the creation of a nonselective, low-resistance shunt between the portal vein and the hepatic vein through which blood is shunted from the portal to the systemic circulation. The procedure is performed by angiographic technique. TIPSs are required in approximately 10% of patients with variceal bleeding. The TIPS procedure can be lifesaving with 90% to 100% of patients achieving hemostasis. A major complication associated with this procedure is the development of hepatic encephalopathy in 10% to 20% of patients as a result of shunting of the blood from the portal to the systemic circulation. Rebleeding occurs in up to 20% of patients within the first month, usually related to occlusion. TIPSs are associated with significantly less morbidity and mortality than surgical decompression. Surgery is considered only when medical and endoscopic therapy fails to control bleeding and a TIPS is not available.

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A major complication of a transjugular intrahepatic portosystemic shunt is acute encephalopathy in 10% to 20% of patients.

B. Lower Gastrointestinal Bleeding

Lower GI hemorrhage can present in a myriad of ways and be self-limiting or life-threatening. In this section, we will focus on the evaluation, diagnosis, and management of clinically significant bleeding.

Lower GI bleeding comprises approximately 20% of all GI bleeds. Five percent to 10% of all GI bleeds are isolated to the small bowel. Common causes of lower GI bleeding include diverticular hemorrhage, angioectasia, post-polypectomy bleeding, ischemia, polyps, neoplasia, inflammatory bowel disease, Meckel's diverticulum, rectal ulcers, or radiation proctitis.

1. Diagnosis

Diagnosis of a GI bleed can be diagnosed with fecal occult blood testing or observation of blood expelled from the rectum. The color of the output may range from bright red to maroon or black. Hematochezia commonly emanates from a lower GI source, but can result from a brisk upper GI bleed. Black stool is also likely from an upper GI source but can result from the small bowel or right colon as well.

> *The source of blood expelled from the rectum may be from an upper gastrointestinal location regardless of color of output.*

a. Laboratory Values

Laboratory values may be altered in the patient with GI bleeding. Hemoglobin and hematocrit (H&H) will likely demonstrate anemia. Early in the course of the bleeding, the H&H may remain normal. Blood urea nitrogen (BUN) can be elevated in the absence of acute renal disease. An elevated BUN to creatinine ratio of greater than 30:1 could be indicative of an upper GI source.

b. Radionuclide Scans

Multiple radiologic modalities are available for diagnosis and/or localization of the source of the GI hemorrhage. Radionuclide scans have a high sensitivity and detect bleeding at 0.05 to 0.1 mL/min. This study is not specific because localization is not as precise as with other modalities. The most common radionuclide study is the technetium-99m (Tc-99m) red blood cell scan. Angiography should be performed immediately after a positive result to maximize the odds of a positive angiography. If the study is negative, repeat imaging can be performed without repeat Tc-99m dosing should the patient again demonstrate signs of hemorrhage.

An uncommon source of lower GI hemorrhage is a Meckel's diverticulum. This can be diagnosed with a Meckel's scan, a radionuclide scan using technetium-99m pertechnetate, which illustrates the gastric mucosa found in the diverticulum.

c. Computed Tomography Scan

A contrast-enhanced computed tomography (CTA) scan can detect bleeding at a rate as low as 0.3 mL/min. Sensitivity is improving with continued development in technology. CTA is often more timely and specific than a Tc-99m study but does require administration of contrast, potentially increasing the prevalence of contrast-induced nephropathy. This should be taken into account if consideration is being made for transcatheter angiography for treatment because further contrast will need to be administered.

Computed tomographic enterography (CTE) can be used to diagnose small bowel bleeding after a negative capsule endoscopy or in those patients in which capsule endoscopy is contraindicated (inflammatory bowel disease, history of radiation, small bowel surgery, or stenosis of the small bowel). There is an increase in the localization of masses in the small bowel compared with video capsule endoscopy. (See discussion on capsule endoscopy.)

d. Angiography

Transcatheter arteriography (TCA) can detect bleeding at a rate of 0.5 to 1.0 mL/min, a higher rate than a Tc-99m study or CTA. Therefore, negative angiography is common after a positive initial study. Source identification is obtained in 25% to 70% of cases. Provocative angiography can be performed. This involves the infusion of anticoagulants, vasodilators, or thrombolytics to increase the likelihood of bleeding. Identification occurs in 31% to 89% of cases of provocative angiography. Angiography can be more beneficial in the patient with the massive GI bleed because diagnosis and intervention can be performed via catheter-directed therapy. It is the preferred initial test if the patient is hemodynamically unstable or has received a transfusion of greater than 5 units of packed red blood cells.

e. Endoscopy

Endoscopic evaluation of the small bowel and colon can be performed as standalone studies or in conjunction with radiographic modalities. Per the ACG, a colonoscopy should be performed as the initial diagnostic procedure for nearly all patients presenting with acute lower GI bleeding. Colonoscopy can be a diagnostic and also therapeutic modality. In lower GI bleeds, 48% to 90% can be localized with colonoscopy. It is imperative to intubate the ileocecal valve and examine the terminal ileum during the procedure to rule out a more proximal source of bleeding. Bowel preparation should be performed when able because this can improve localization and decreases the rate of colon perforation. A nasogastric tube may be placed to aid in administration of the solution. Large-volume tap water enemas may also be given to allow better visualization.

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More than half of lower gastrointestinal bleeds can be localized using colonoscopy. Bowel preparation improves visualization.

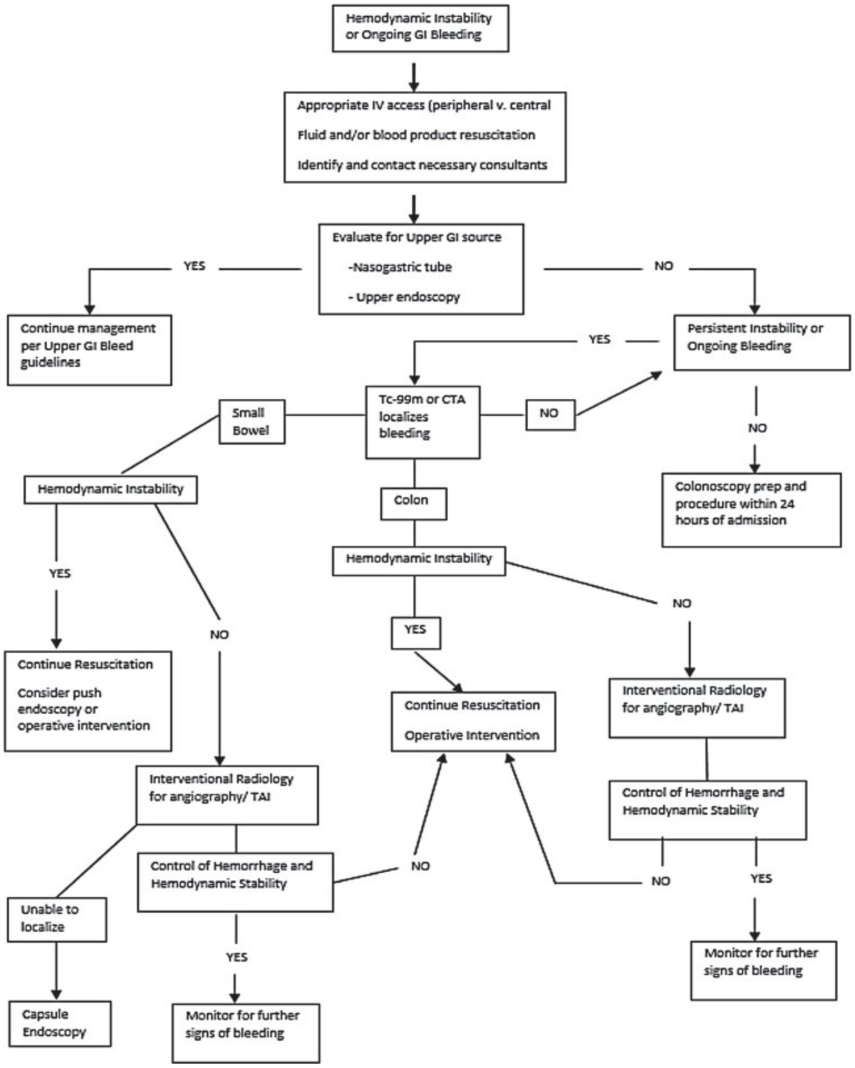
Push enteroscopy is usually performed with a pediatric colonoscope and can reach up to 150 cm from the ligament of Treitz. This can diagnose up to 70% of lesions which are usually vascular in nature. This is considered a second-look endoscopy and the majority of identified lesions are in a location that are visualized on standard upper endoscopy.

Video capsule endoscopy (VCE) has emerged as the diagnostic test of choice for small bowel bleeding. The source of bleeding is identified in 38% to 83% of patients with high positive and negative predictive values, 94% to 97% and 83% to 100%, respectively. Performing the examination within 2 weeks of the bleeding episode increases localization from 34% to 91%, with the greatest yield within the first 72 hours. VCE should be performed if other imaging modalities have been used without achieving localization of the bleeding source.

2. Treatment

Therapeutic modalities for lower GI bleed include interventions in the radiology suite, GI lab, and operating room. Medical management of lower GI bleeding can include the use of somatostatin analogs, which can lead to a decreased need for blood transfusion in refractory bleeding (**Figure 14-6**). Transcatheter angiography can be immediately followed by intervention during the same procedure. Super-selective embolization (SSE) succeeds in obstructing the bleeding source in 73% to 100% of cases. Clinical success (defined as cessation of bleeding without early rebleeding) is achieved in 63% to 96% of cases. Secondary clinical success rate (after a second angioembolization) is 79%. Transcatheter angiographic intervention (TAI) provides definitive treatment in 81% to 86% of patients. Rebleeding is more common in small bowel sources as a result of the large amount of collateral vessels present. Embolization does frequently result in minor ischemic injury to the bowel, but major events occur in 4% of the cases.

Figure 14-6. Algorithm for the Management of Lower Gastrointestinal Bleeding


Hemodynamic Instability or Ongoing GI Bleeding
Appropriate IV access (peripheral v. central
Fluid and/or blood product resuscitation
Identify and contact necessary consultants
Evaluate for Upper GI source
-Nasogastric tube
- Upper endoscopy
YES
NO
Continue management per Upper GI Bleed guidelines
Persistent Instability or Ongoing Bleeding
YES
NO
Tc-99m or CTA localizes bleeding
Small Bowel
NO
Colonoscopy prep and procedure within 24 hours of admission
Hemodynamic Instability
Colon
Hemodynamic Instability
YES
NO
NO
YES
Continue Resuscitation
Consider push endoscopy or operative intervention
Continue Resuscitation
Operative Intervention
Interventional Radiology for angiography/ TAI
Interventional Radiology for angiography/ TAI
Control of Hemorrhage and Hemodynamic Stability
Control of Hemorrhage and Hemodynamic Stability
NO
NO
YES
Unable to localize
YES
Capsule Endoscopy
Monitor for further signs of bleeding
Monitor for further signs of bleeding

Interventions in the endoscopy suite can be performed at the time of the diagnostic evaluation via colonoscopy or push enteroscopy. Application of clips, argon plasma coagulation, electrocoagulation, banding, and injection of epinephrine are all employed to obtain hemostasis. These modalities are more effective in the large bowel than the small bowel. Up to 46% of patients experienced rebleeding within 36 months in small bowel lesions treated endoscopically.

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In extreme cases, emergent subtotal colectomy can be performed once an upper gastrointestinal source has been ruled out. Persistent hemorrhage after this suggests a small bowel source.

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Surgical intervention is usually reserved for cases in which the location of bleeding has definitively been located. In extreme cases, emergent subtotal colectomy can be performed once an upper GI source has been ruled out. If an emergent subtotal colectomy is performed and continued hemorrhage is encountered, the small bowel is the most likely source of bleeding. Surgical resection is the treatment of choice for the bleeding Meckel's diverticulum.

IV. INTRA-ABDOMINAL HYPERTENSION AND ABDOMINAL COMPARTMENT SYNDROME

Intra-abdominal pressure (IAP) is a steady-state pressure contained within the abdominal cavity. Normal IAP ranges from 5–7 mm Hg. However, patients with morbid obesity and individuals that are pregnant may have higher baseline IAPs. Short periods of increased IAP occur during sneezing, coughing, Valsalva maneuvers, defecation, and weight lifting.

IAP can also vary with spontaneous respirations. In addition, positive inspiratory-expiratory pressures during mechanical ventilation can indirectly increase IAP. Increases in the volume of intra-abdominal contents can also increase IAP. Although it does not increase IAP directly, compliance of the abdominal wall (ie, burns, edema, and prone positioning) may also affect the pressures contained within.

In clinical practice, intraabdominal pressure is almost always measured indirectly via bladder pressures.

Pressures in the abdomen increase with intra-abdominal volume increases or decreased compliance. Massive intravenous fluid resuscitation with capillary leak, positive fluid balance, and rapid increase in visceral edema are directly associated with the development of increased intra-abdominal volumes, thus increasing IAP. No matter what the cause, elevated IAP threatens perfusion and viability of the organs of the intra-abdominal compartment. The terms intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS) represent stages along the spectrum of IAP that affects intra-abdominal tissue viability and organ dysfunction.

1. Diagnosis

IAH is defined by a sustained or repeated pathologic elevation in IAP greater than or equal to 12 mm Hg. In clinical practice, IAP is almost always measured indirectly by way of bladder pressures transduced through an indwelling catheter. This measured pressure correlates well with directly measured IAP. Intermittent bladder pressure measurement equipment is readily available in most ICUs. Grades of IAH are noted in **Table 14-3**. Abdominal compartment syndrome is not graded; it is solely present or absent.

Table 14-3 Grading of Intra-abdominal Hypertension

Normal	5–7 mm Hg
Grade 1	12–15 mm Hg
Grade 2	16–20 mm Hg
Grade 3	21–25 mm Hg
Grade 4	Greater than 25 mm Hg

> *Sustained intra-abdominal pressures greater than 10 mm Hg in the pediatric population constitutes intra-abdominal hypertension.*

Abdominal compartment syndrome is defined as a sustained IAP greater than 20 mm Hg that is associated with new organ dysfunction or failure. In the pediatric population, IAH is defined as sustained or repeated pathologic elevation of IAP greater than 10 mm Hg and ACS defined as IAH with new or worsening organ dysfunction attributable to elevated IAP. IAH and ACS can be further classified as primary, secondary, or recurrent. Primary is when the condition is associated with injury or disease in the abdominal pelvic region that frequently requires surgical or interventional radiologic intervention. Secondary refers to conditions that do not originate from the abdominal pelvic region. Recurrent refers to IAH or ACS that redevelops following previous surgical or medical treatment of the primary or secondary IAH. Many different conditions can lead to IAH and ACS. Risk factors for IAH are listed in **Table 14-4**.

2. Clinical Presentation

Early detection and recognition of IAH is paramount so that it can be treated before progressing to ACS. The presentation of acute IAH is varied, but progressive oliguria and increased ventilatory requirements are common.

Other findings include hypotension, tachycardia, elevated jugular venous pressure, jugular venous distension, peripheral edema, abdominal tenderness, or acute pulmonary decompensation. There may be evidence of hypoperfusion, including cool skin, obtundation, restlessness, or lactic acidosis. Physical examination has a low sensitivity of around 40–60%, but nearly all patients have a tensely distended abdomen.

Table 14-4 Risk Factors

Diminished abdominal wall compliance
Abdominal surgery
Major trauma
Major burns
Prone positioning

Increased intraluminal contents
Gastroparesis, gastric distention
Ileus
Colonic pseudo-obstruction
Volvulus

Increased intra-abdominal contents
Acute pancreatitis
Hemoperitoneum/pneumoperitoneum
Intra-abdominal infection/abscess
Intra-abdominal or retroperitoneal acute tumors
Laparoscopy with excessive insufflation
Liver dysfunction/cirrhosis with ascites
Peritoneal dialysis

Capillary leak/fluid resuscitation
Acidosis
Damage control laparotomy
Hypothermia
Increased APACHE-II or SOFA score
Massive fluid resuscitation or positive fluid balance
Massive transfusion

Others/miscellaneous
Age
Bacteremia
Coagulopathy
Massive incisional hernia repair
Mechanical ventilation, especially with PEEP of greater than 10
Obesity or increased BMI
Peritonitis
Sepsis
Shock plus/minus hypotension

Abbreviations: APACHE II, Acute Physiology and Chronic Health Evaluation II, BMI, body mass index, PEEP, positive end-expiratory pressure, SOFA, Sequential Organ Failure Assessment

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IAH and ACS can have effects both intra-abdominally and extra-abdominally. Some of these effects are directly associated with the pressure causing impaired perfusion of the abdominal organs, while other effects are the result of the change in thoraco-abdominal compliance.

- Gastrointestinal tract: Increased vascular resistance of the splanchnic vessels leads to hypoperfusion and visceral ischemia, potentially leading to bacterial translocation and lactic acid production.
- Renal: Direct compression of the renal parenchyma and compression of renal vessels resulting in increased venous congestion and decreased arterial perfusion that can activate the renin-angiotensin system leading to oliguria and acute kidney injury.
- Cardiovascular: Inferior vena cava compression which can decrease the preload; decreased arterial outflow to the lower extremities; increase in right ventricular afterload; decreased cardiac output.
- Respiratory: Decreased functional residual capacity; increased ventilation/perfusion mismatch; increased intrathoracic pressures during mechanical ventilation.
- Central nervous system: Impaired venous return from the brain as a result of increased jugular venous pressures which may result in increased intracranial pressure.

Abdominal compartment syndrome can affect both intra-abdominal and extra-abdominal organ systems.

!

3. Management

Early detection of IAH and ACS remains the mainstay of optimal management. The use of serial monitoring is recommended in any patient at risk. Supportive care should consist of maintaining adequate perfusion with prompt intervention with medical therapies designed to decrease rising intra abdominal pressure. These therapies include the following examples.

- Improving abdominal wall compliance: optimize sedation and analgesia; avoid elevation of head of bed greater than 30 degrees; remove constrictive dressings; escharotomies; and use of neuromuscular blockers.
- Evacuation of intra-luminal contents: nasogastric decompression; prokinetic agents; rectal decompression; decrease or discontinue enteral nutrition; enemas; and colonoscopic decompression.
- Evacuation of abdominal fluid collections: paracentesis; percutaneous drainage of fluid collections/abscesses; and surgical evacuation.
- Correct fluid balance: avoid excessive fluid; aim for zero to negative balance; diuresis; and renal replacement therapy.
- Optimize systemic and regional perfusion: use of goal directed therapies; and hemodynamic monitoring devices to guide resuscitation.

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Decompressive laparotomy remains the standard and most definitive treatment for abdominal *compartment syndrome.*

!

Surgical treatment, the decompressive laparotomy, remains the gold standard and most definitive treatment for ACS. However, even after a decompressive laparotomy is performed, the procedure does not prevent recurrent intra-abdominal hypertension. The temporary abdominal closure device used to protect the viscera can result in a constrictive bandage that decreases abdominal wall compliance and can allow for increased IAP.

Key Points

Abdominal Surgical Emergencies: Part 2

- Although no current scoring system exists to accurately predict patients at risk for severe acute pancreatitis, stratification of severity remains important.
- Antibiotic prophylaxis is not recommended to prevent infected pancreatic necrosis.
- Oral feeding is feasible and recommended if the patient can tolerate; otherwise, enteral tube feedings should be instituted.
- Upper gastrointestinal bleeding originates proximal to the ligament of Treitz, and lower gastrointestinal bleeding originates distal to the ligament of Treitz.
- Medical treatment has greatly decreased the incidence of upper gastrointestinal bleeding with endoscopy being the mainstay of treatment refractory to medical treatment.
- Localization of the site of the lower gastrointestinal bleeding will help determine the management pathway.

- Intra-abdominal pressures should be measured via bladder pressures early in patients at risk for intra-abdominal hypertension and abdominal compartment syndrome.
- Treatment to maintain abdominal organs perfusion and methods to mediate and prevent increasing intra-abdominal pressure should be instituted early in patients with intra-abdominal hypertension.
- Decompressive laparotomy remains the most definitive treatment for abdominal compartment syndrome but does not obviate the risk of recurrent abdominal compartment syndrome.

Suggested Readings

1. Banks PA, Bollen TL, Dervenis C, et al. Classification of acute pancreatitis—2012: revision of the Atlanta classification and definitions by international consensus. *Gut*. 2013;62(1):102-111.
2. Chaptiti L, Peikin S. Gastrointestinal Bleeding. In Parrilo JE, Dellinger RP, eds. *Critical Care Medicine*. 4th ed. Philadelphia, PA: Saunders Elsevier; 2014; Chapter 76.
3. Coccolini F, Montori G, Ceresoli M, et al. The role of open abdomen in non-trauma patient: WSES Consensus Paper. *World J Emerg Surg*. 2017;12:39.
4. Darcy MD, Cash BD, Feig BW, et al. Appropriateness Criteria-Radiologic Management of Lower GI Tract Bleeding. American College of Radiology. https://acsearch.acr.org/docs/69457/Narrative/
5. Evans RPT, Mourad MM, Pall G, et al. Pancreatitis: Preventing catastrophic haemorrhagic. *World J Gastroenterol*. 2017;23(30):5460-5468.
6. Forsmark CE, Vege SS, Wilcox CM. Acute pancreatitis. *N Engl J Med*. 2016;375(20):1972-1981.

7. Feinman M, Haut ER. Upper gastrointestinal bleeding. *Surg Clin North Am*. 2014:94(1):43-53.

8. Gerson LB, Fidler JL, Cave DR, Leighton JA. ACG Clinical Guideline: Diagnosis and Management of Small Bowel Bleeding. *Am J Gastroenterol*. 2015;110(9):1265-1287.

9. Kirkpatrick AW, Roberts DJ, De Waele J, et al. Intra-abdominal hypertension and the abdominal compartment syndrome: updated consensus definitions and clinical practice guidelines from the World Society of the Abdominal Compartment Syndrome. *Intensive Care Med*. 2013;39(7):1190-206.

10. Maheshwari R, Subramanian RM. Severe acute pancreatitis and necrotizing pancreatitis. *Crit Care Clin*. 2016;32(2):279-290.

11. Rahman SI, Saeian K. Nonvariceal upper gastrointestinal bleeding. *Crit Care Clin*. 2016:32(2):223-239.

12. Rogers WK, Garcia L. Intraabdominal Hypertension, Abdominal Compartment Syndrome, and the Open Abdomen. *Chest*. 2018;153(1):238-250.

13. Strate LL, Gralnek IM. ACG Clinical Guideline: Management of Patients with Acute Lower Gastrointestinal Bleeding. *Am J Gastroenterol*. 2016:111(4):459-474.

14. Tavakkolizadeh A, Ashley S, Acute Gastrointestinal Hemorrhage. In: Townsend CM, Beauchamp RD, Evers BM, Mattox KL, eds. Sabiston Textbook of Surgery. 9th ed. Philadelphia, PA: Saunders Elsevier; 2012; Chapter 48.

15. van Brunschot S, van Grinsven J, van Santvoort HC, et al. Endoscopic or surgical step-up approach for infected necrotising pancreatitis: a multicentre randomised trial. *Lancet*. 2018;391(10115):51-58.

16. Wybourn C, Campbell A. Gastrointestinal Bleeding. In: Vincent JL, Abrahm E, Moore FA, Kochanek PM, Fink MP, eds.

Textbook of Critical Care. 7th ed. Philadelphia, PA: Elsevier; 2017: Chapter 24.

Suggested Websites

1. American Pancreatic Association. https://www.american-pancreatic-association.org
2. American College of Gastroenterology. http://www.gi.org
3. WSACS - the Abdominal Compartment Society. http://www.wsacs.org
4. EMCrit Blog – Emergency Department Critical Care & Resuscitation. https://emcrit.org/emcrit/blakemore-tube-placement/

Chapter 15

ACUTE CORONARY SYNDROMES

Objectives

- Identify patients who have acute coronary syndromes with various electrocardiographic and clinical presentations.
- Outline diagnostic procedures and the acute management of non–ST-elevation acute coronary syndrome (NSTE-ACS) and ST-elevation myocardial infarction (STEMI).
- Identify appropriate reperfusion interventions for patients with STEMI and high-risk patients with NSTE-ACS.
- Recognize the complications of myocardial infarction and outline the appropriate management.

Case Study

A 58-year-old man with a long-standing history of type 2 diabetes mellitus and hyperlipidemia develops sudden-onset severe chest pain while mowing grass. It was associated with dyspnea, nausea, and diaphoresis. His vital signs on arrival in the emergency department are as follows: blood pressure of 148/84 mm Hg, heart rate of 94 beats/min, respiratory rate of 26 breaths/min, and oxygen saturation measured by pulse oximetry of 97% on room air. His physical examination is remarkable only for dyspnea and mild diaphoresis.

– What features make acute coronary syndrome more likely to have occurred?

– What information is needed to determine whether this patient has an acute coronary syndrome?

– What are the recommended immediate management/interventions?

I. INTRODUCTION

Acute coronary syndrome (ACS) refers to a group of conditions characterized by acute myocardial ischemia resulting from reduction in myocardial blood flow. An important distinction is made clinically on the basis of an electrocardiogram (ECG) between patients with ACS who have ST-elevation myocardial infarction (STEMI), who should be considered for immediate revascularization, and those who do not (non–ST-elevation acute coronary syndrome [NSTE-ACS]). ACSs account for nearly 2 million hospitalizations annually in the United States, and, if patients who die before reaching the hospital are included, mortality may be as high as 25%.

ACSs share similar pathogenic mechanisms and represent different points along a common continuum. ACSs are usually precipitated by rupture of an atherosclerotic plaque, leading to a complex process of inflammation, platelet activation and aggregation, thrombus formation, and microembolization to the distal vasculature that results in decreased myocardial oxygen supply. Plaque erosion may play a role in some patients with NSTE-ACS. Possible sequelae of plaque rupture include thrombus formation with total occlusion, with ST-elevation myocardial infarction; dissolution of thrombus and healing of the fissure, with clinical stabilization; and subtotal occlusion, which can lead to either NSTE-ACS or unstable angina.

The distinction between NSTE-ACS and unstable angina is made on the basis of biochemical evidence of myocardial injury manifested as elevation of cardiac troponin. Such injury confers a higher risk and is usually an indication for coronary revascularization. Patients without elevated troponins are said to have unstable angina. The spectrum of ACS is shown in **Figure 15-1**.

!

Be aware of changes in the management of ACS as new evidence becomes available.

!

It is important to recognize that other conditions can increase cardiac troponin. The Universal Definition of Myocardial Infarction makes a distinction between troponin elevation consequent to plaque rupture or erosion (Type 1 MI) and troponin elevation that is the result of an imbalance between myocardial demand and supply (Type 2 MI), which is treated differently, usually by addressing the underlying hemodynamic precipitant. Inflammatory, infectious, renal failure, and other conditions can lead to elevated troponin levels not related to myocardial ischemia.

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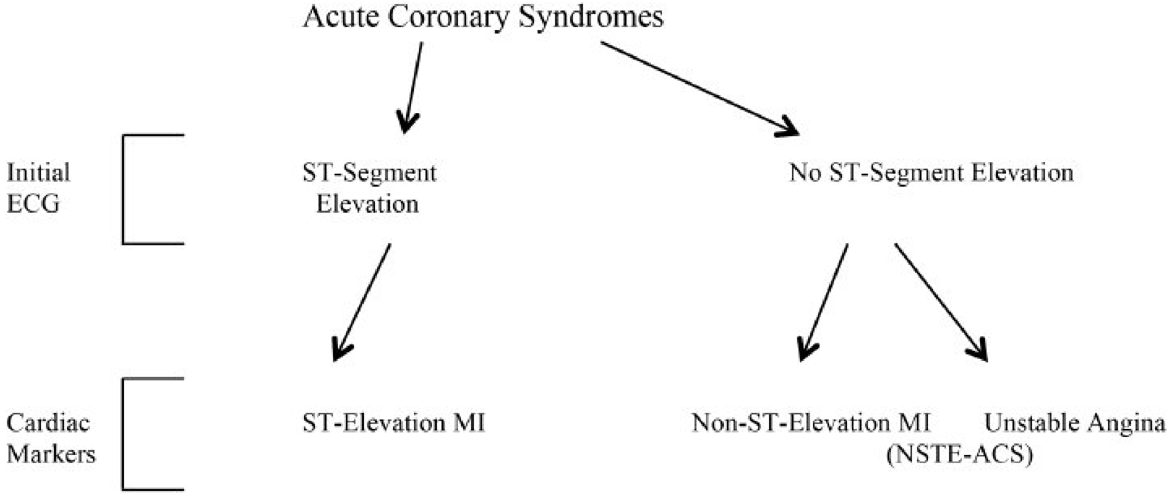
A multidisciplinary team approach is important in the recognition and management of patients with ACS.

!

Patients presenting with chest discomfort should be evaluated expeditiously for life-threatening conditions, including not only ACS but also other conditions such as pulmonary embolism and aortic dissection; those conditions should be treated promptly when diagnosed. An ECG should be obtained and interpreted within 10 minutes of presentation. Results are best when an organized approach to triage and diagnosis of suspected ACS is employed. Hospitals should establish multidisciplinary teams (including primary care physicians, emergency medicine physicians, cardiologists, nurses, and others) to develop evidence-based protocols for triaging and managing patients with symptoms suggestive of ACS. These protocols must be updated periodically based on the best current evidence.

Figure 15-1. Overlapping Spectrum of Acute Coronary Syndromes


Acute Coronary Syndromes
Initial ECG
ST-Segment Elevation
No ST-Segment Elevation
Cardiac Markers
ST-Elevation MI
Non-ST-Elevation MI
Unstable Angina
(NSTE-ACS)

Abbreviations: ECG, electrocardiogram; MI, myocardial infarction; NSTE-ACS, non–ST-elevation acute coronary syndrome

Acute coronary syndromes are distinguished by initial ECG findings and cardiac markers. The term NSTE-ACS is preferred to non-ST elevation MI because the latter does not distinguish between Type 1 and Type 2 myocardial infarction (see text).

The consequences of ACS are often so severe that therapy is indicated even when the diagnosis is presumptive.

Patients with other critical illness or injury have an increased risk for ACS and frequently have atypical presentations. Definitive diagnosis of ACS may not be possible on initial evaluation and requires continuous observation, ECG monitoring, and/or laboratory evaluations. The initial physical examination should include vital signs and general observation, assessment of jugular venous distension, auscultation of the lungs and heart, evaluation of the peripheral pulses, detection of neurologic deficits, and assessment for evidence of systemic hypoperfusion.

II. NON—ST-ELEVATION ACUTE CORONARY SYNDROME

If ST elevation is not present on the presenting ECG, the likelihood that symptoms represent ACS can be evaluated based on an assessment of risk factors for coronary artery disease (**Table 15-1**), the history and presenting symptoms, physical examination, the ECG, and biochemical markers. Accelerated diagnostic pathways using validated risk scores can augment the accuracy of clinical judgment and can be beneficial to assess prognosis.

Table 15-1 Risk Factors for Coronary Artery Disease

- Family history of myocardial infarction
- Hypertension
- Smoking history
- Hyperlipidemia
- Increasing age
- Postmenopausal state
- Obesity
- Diabetes mellitus
- Other vascular disease
- Sedentary lifestyle
- Cocaine/amphetamine use

At presentation, patients with ischemic-type chest pain and an ECG with no ST-segment elevation are presumed to have NSTE-ACS. Other causes of prolonged chest pain (**Table 15-2**) should also be considered. Myocardial damage is assessed using biochemical markers of cardiac injury.

Table 15-2 Differential Diagnosis of Prolonged Chest Pain

- Acute myocardial ischemia
- Aortic dissection/aortic aneurysm
- Myocarditis
- Pericarditis
- Pain associated with hypertrophic cardiomyopathy or esophageal and gastrointestinal disorders
- Pulmonary diseases such as pneumothorax, pulmonary embolism, and pleuritic
- Hyperventilation syndrome
- Aortic stenosis
- Musculoskeletal or chest wall diseases, costochondral pain
- Psychogenic pain

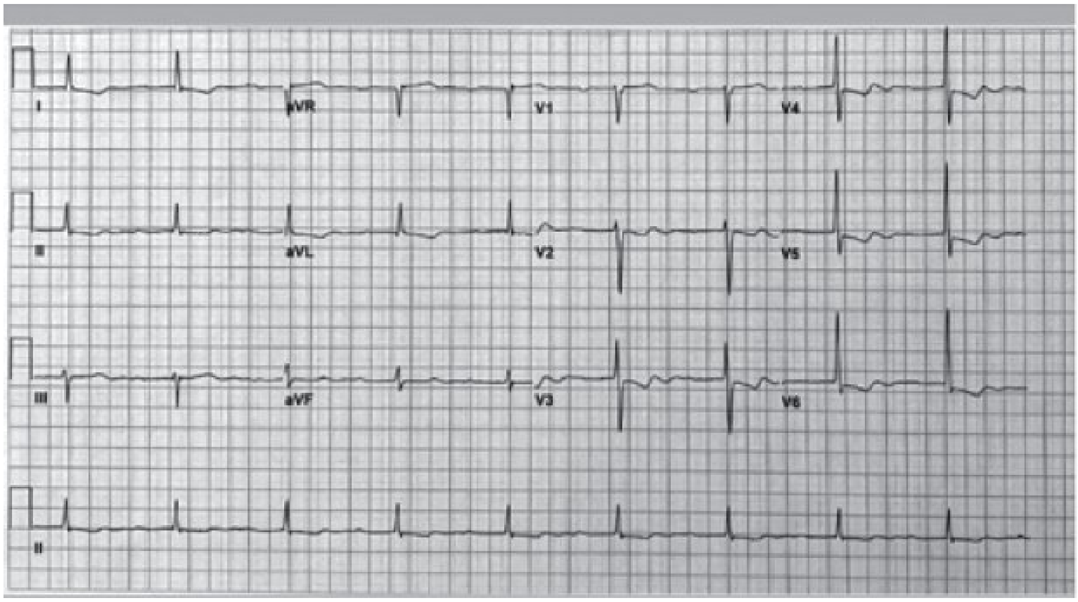
Data taken from the Agency for Healthcare Research and Quality. Braunwald E, Mark DB, Jones RH, et al. Unstable angina: diagnosis and management. AHCPR Publication 94-0602. Rockville, MD: Agency for Health Care Policy and Research and National Heart, Lung, and Blood Institute; 1994.

A. Diagnosis

The most important factors that suggest the likelihood of myocardial ischemia are the character of the pain, prior history of coronary artery disease, age, and number of risk factors. Results of the physical examination may be normal, although a fourth heart sound (S4) may be heard during episodes of pain. A 12-lead ECG is most helpful if it shows ST-segment depression (**Figure 15-2**) during anginal episodes, especially if those changes are dynamic and relieved by nitrates, but the ECG may be normal or may reveal nondiagnostic T-wave inversions or peaked T waves.

Some patients may not have classic features of ACS. Patients with diabetes mellitus may not feel chest discomfort but rather present with dyspnea or other atypical symptoms. Elderly patients with ACS may present only with lethargy, irritability, or altered mental status.

Figure 15-2. Electrocardiogram of a Patient With NSTE-ACS



The ST-segment depression is characteristic of non–ST-elevation acute coronary syndrome. Courtesy of Kehllee Popovich, ACPN, MSN

Some women may not present with typical left-sided pressure or squeezing-type chest pain but may have nonspecific symptoms often described more as discomfort rather than pain. Women also have a greater prevalence of other features such as nausea, shortness of breath, palpitations, jaw and neck pain, as well as back pain. Nonetheless, chest pain remains the predominant symptom reported in those ultimately diagnosed with ACS, with the frequency in women equal to men.

If equipment and expertise are available, the use of transthoracic echocardiography allows bedside assessment of wall motion abnormalities as a marker for current or past ischemia and the detection and follow-up of new abnormalities. It also provides an estimate of left ventricular (LV) function and identification of valvular dysfunction and/or pericardial fluid.

!

New-onset shortness of breath and/or new left bundle branch block should be considered possible evidence of ACS, particularly in women and patients with *diabetes mellitus, who may have atypical presentations.*

The differential diagnosis of chest pain is broad and includes aortic dissection or aneurysm, myocarditis, pericarditis, aortic stenosis, pulmonary embolism, pneumothorax, esophageal and gastrointestinal disorders, pneumonia, pleuritic pain, musculoskeletal or chest wall diseases, hyperventilation, and other causes. Additional tests, such as hemoglobin/hematocrit, electrolytes, thyroid function, and arterial oxygen saturation, may be helpful in identifying precipitating factors for demand ischemia or ACS, or may identify alternate diagnoses. Other imaging tests may be indicated as warranted by the clinical presentation.

Several risk-stratification scores have been developed and validated to assist in predicting the risk of death and ischemic events in NSTE-ACS. The GRACE 2.0 (Global Registry for Acute Cardiac Events) score (https://www.outcomes-umassmed.org/risk_models_grace_orig.aspx) requires an app or a web-based calculator, whereas the TIMI (Thrombolysis in Myocardial Infarction) risk score can be easily determined at the bedside (**Table 15-3**). High-risk patients are considered to have a greater than 6% risk of dying within 6 months, and intermediate-risk patients have a 6-month mortality rate of 3% to 6%. Risk assessment has implications for the location of care, selection of medical therapy, and use of reperfusion interventions.

Table 15-3 TIMI Risk Score for Adverse Cardiac Events

1 point for each:

- Age ≥65 y
- Known coronary artery disease (coronary stenosis ≥50%)
- ST-segment deviation of at least 0.5 mm
- At least 2 angina events in prior 24 hours
- Use of aspirin in prior 7 days
- At least 3 risk factors for coronary artery disease (family history of premature coronary artery disease, hypertension, hyperlipidemia, diabetes mellitus, smoking)
- Elevated serum cardiac markers

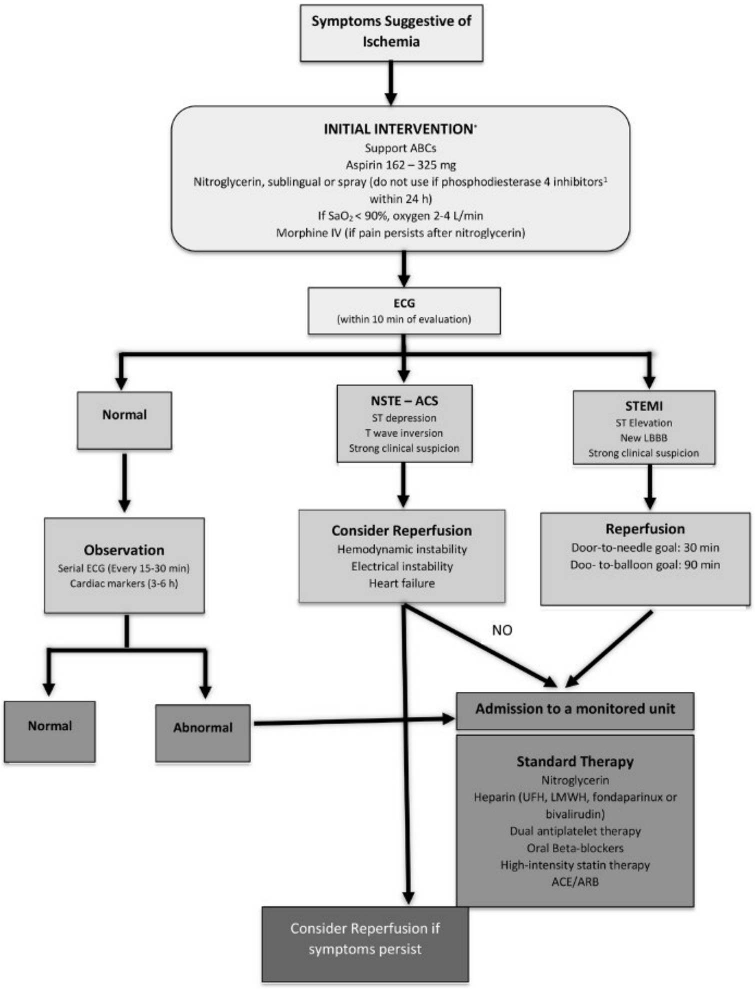
Risk Factors	Score	Risk of Adverse Cardiac Event
Low	0-2	5% to 8%
Intermediate	3-4	13% to 20%
High	5-7	26% to 41%

Abbreviation: TIMI, thrombolysis in myocardial infarction

B. Management

Reversing myocardial ischemia and confirming the diagnosis of NSTE-ACS are the initial priorities. Patients with NSTE-ACS should be admitted to a unit with cardiac monitoring and placed on bed or chair rest (**Figure 15-3**). Emerging data suggest that routine use of supplemental oxygen in cardiac patients with normal oxygenation may have untoward effects, but patients with hypoxemia (oxygen saturation measured by pulse oximetry < 90% on room air), respiratory distress, heart failure, or shock should receive oxygen by nasal cannula. If precipitating, reversible causes, such as fever, anemia, hypoxemia, infection, hypertension, anxiety, hyperthyroidism, arrhythmias, or sympathomimetic drug ingestion (eg, cocaine, amphetamines) can be identified, they should be treated aggressively. Further management includes anti-ischemic therapy, therapy for platelet aggregation/thrombosis, ongoing risk stratification, and consideration of invasive reperfusion procedures.

Figure 15-3. Evaluation and Treatment of Acute Coronary Syndromes


Symptoms Suggestive of Ischemia
INITIAL INTERVENTION*
Support ABCs
Aspirin 162 – 325 mg
Nitroglycerin, sublingual or spray (do not use if phosphodiesterase 4 inhibitors¹ within 24 h)
If SaO_2 < 90%, oxygen 2-4 L/min
Morphine IV (if pain persists after nitroglycerin)
ECG
(within 10 min of evaluation)
Normal
NSTE – ACS
ST depression
T wave inversion
Strong clinical suspicion
STEMI
ST Elevation
New LBBB
Strong clinical suspicion
Observation
Serial ECG (Every 15-30 min)
Cardiac markers (3-6 h)
Consider Reperfusion
Hemodynamic instability
Electrical instability
Heart failure
Reperfusion
Door-to-needle goal: 30 min
Doo- to-balloon goal: 90 min
NO
Normal
Abnormal
Admission to a monitored unit
Standard Therapy
Nitroglycerin
Heparin (UFH, LMWH, fondaparinux or bivalirudin)
Dual antiplatelet therapy
Oral Beta-blockers
High-intensity statin therapy
ACE/ARB
Consider Reperfusion if symptoms persist

*Intervention by emergency medical services or in the emergency department

[1] sildanefil, vardenafil, tadalafil

Abbreviations: ABCs, airway, breathing, circulation; ACE, angiotensin converting enzyme inhibitor; ARB, angiotensin receptor blocker; ECG, electrocardiogram; LBBB, left bundle branch block; LMWH, low-molecular-weight heparin; NSTE-ACS, non–ST-elevation acute coronary syndrome; STEMI, ST-elevation myocardial infarction; UFH, unfractionated heparin

1. Anti-ischemic Therapy

Immediate control of ischemic pain is typically accomplished with a combination of nitrates, β-blockers, and opiates. Antianginal medications that are effective in stabilizing patients with unstable angina are listed in **Table 15-4**. The goal is to reduce ischemia without causing hypotension or reflex tachycardia. Patients with ongoing ischemic discomfort should receive up to three doses of sublingual or spray nitroglycerin. Nitrates should not be administered if the systolic blood pressure measures < 90 mm Hg or ≥ 30 mm Hg below the patient's baseline blood pressure. Additional contraindications to nitrate administration are a heart rate of < 50 beats/min, tachycardia > 100 beats/min in the absence of heart failure symptoms, and in suspected right ventricular infarction or severe aortic stenosis. Nitrates are also contraindicated in patients who have received a phosphodiesterase inhibitor for erectile dysfunction in the previous 24 hours (48 hours for tadalafil).

Table 15-4 Anti-ischemic Therapy

Agent	Oral Dose	Spray Dose	Intravenous Dose
Nitroglycerin	0.4–mg tablet sublingually to a maximum of 3 doses; contraindicated when systolic blood pressure <90 mm Hg	0.4 mg every 5 min to a maximum of 3 doses; contraindicated when systolic blood pressure <90 mm Hg	Initial infusion rate 10 μg/min; increases of 10 μg/min every 3–5 min as needed to control pain; discontinue rate increases for significant drops in blood pressure or maximum of 200 μg/min
Morphine sulfate			1–5 mg every 5–30 min as needed for pain
Metoprolol	50–200 mg every 24 h		5 mg every 5 min to a total dose of 15 mg
Carvedilol	6.25 mg every 12 h titrated to maximum 25 mg every 12 h		
Propranolol	20–80 mg every 6–8 h 40–100 mg every 12 h		0.5–1 mg as single dose 5 mg every 5 min to total dose of 15 mg
Diltiazem	30–60 mg every 6–8 h		

Prominent hypotension with administration of nitroglycerin should raise the suspicion of right ventricular infarction.

If sublingual or spray nitroglycerin does not relieve pain, an assessment should be made about the need for IV nitroglycerin for persistent ischemia. Decreases in blood pressure with nitroglycerin are predominantly the result of increased venous capacitance and can often be treated with careful IV crystalloid infusion, but if the systolic pressure falls below 110 mm Hg in normotensive patients, the nitroglycerin dose should not be increased. Tolerance to the hemodynamic effects of nitroglycerin becomes important after 24 hours of continuous infusion, and efforts should be made to switch to other dosing regimens. The dose of IV nitrates should be tapered and discontinued when ischemic manifestations have resolved for 12 to 24 hours.

Morphine sulfate is a reasonable analgesic for management of pain refractory to initial antianginal therapy. Nonsteroidal anti-inflammatory drugs other than aspirin should be discontinued during hospitalization.

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Aspirin improves survival and reduces the incidence of MI.

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Routine use of IV β-blockers in the initial management of patients with suspected NSTE-ACS is not supported by current evidence, but may be considered in patients with ongoing chest pain, especially with concomitant hypertension or tachycardia; IV dosing should be followed by oral administration. IV β-blockers are contraindicated in patients with shock, heart rate < 50 beats/min, decompensated heart failure, advanced heart block (type II second-degree or third-degree), hypotension, or active bronchospastic disease. Caution is advised with the use of β-blockers in patients with risk factors for shock (age > 70 years, heart rate > 110 beats/min, systolic blood pressure < 120 mm Hg, or late presentation).

Oral β-blockers should be initiated within the first 24 hours in patients when possible; an attempt should be made to start even in patients with initial contraindications to their use.

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Avoid use of diltiazem in cases of reduced left ventricular function.

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Non-dihydropyridine calcium channel blockers (eg, diltiazem, verapamil) do not reduce mortality risk in myocardial infarction (MI). In the absence of contraindications (such as significant LV dysfunction), they may be considered only if patients cannot tolerate a β-blocker or symptoms are not controlled with nitroglycerin and β-blockers together.

2. Antiplatelet Therapy

The use of antiplatelet and anticoagulant agents (**Table 15-5**) is important in patients with NSTE-ACS because of the contributions of platelet activation/aggregation and the coagulation system to platelet-rich thrombus formation. Dual antiplatelet therapy is indicated in patients undergoing revascularization with percutaneous coronary intervention (PCI). The intensity of therapy with these agents is often tailored to the patient's risk assessment and to plans for early invasive procedures. Non–enteric-coated aspirin at a dose of 162 to 325 mg should be administered (and chewed) as soon as possible to all patients with NSTE-ACS (including those in the prehospital setting) if no aspirin allergy is suspected. Aspirin should be administered indefinitely. Clopidogrel or ticagrelor should be considered as an alternative antiplatelet agent if aspirin is contraindicated.

Table 15-5 Antiplatelet Drugs Used in Acute Coronary Syndromes

Antiplatelet Agents	
Aspirin	162-325 mg chewed and swallowed initially, then 81-325 mg as a minimum oral dose daily
P_2Y_{12} antagonists	
Clopidogrel	Loading dose of *75–300 mg orally can be used with a noninvasive approach or fibrinolysis; loading dose of 300 to 600 mg orally with PCI; maintenance dose of 75 mg orally daily
Prasugrel	Loading dose of 60 mg orally may substitute for clopidogrel in patients with STEMI managed with early PCI who are not at high risk of bleeding; maintenance dose of 10 mg daily (consider 5 mg daily if weight <60 kg); not studied for STEMI treated with fibrinolysis
Ticagrelor	Loading dose of 180 mg orally may be an option instead of clopidogrel in NSTE-ACS or STEMI managed with early PCI; maintenance dose of 90 mg twice daily; not studied for STEMI treated with fibrinolysis

Abbreviations: P_2Y_{12}, The P_2Y_{12} receptor is the predominant receptor involved in the ADP-stimulated platelet activation; PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction; NSTE-ACS, non–ST-elevation acute coronary syndrome

*Individuals > 75 years of age, and those receiving fibrinolysis, should receive a loading dose of 75 mg because of increased bleeding risk

If an early invasive strategy (angiography within 24–48 hours with revascularization if appropriate) or noninterventional conservative approach is planned, clopidogrel or ticagrelor should be added to aspirin to decrease the risk of cardiovascular death, MI, and stroke. Clopidogrel, prasugrel, or ticagrelor should be administered in patients undergoing PCI, but prasugrel is contraindicated in those with a history of stroke or transient ischemic attack and is associated with an increased risk of bleeding. The choice of a specific adenosine diphosphate inhibitor should be discussed with the cardiologist when possible.

3. Anticoagulant Therapy

The combination of aspirin and an anticoagulant agent is more beneficial than aspirin alone in NSTE-ACS. The selection of a specific agent should take into account the risks of ischemia and bleeding complications, as well as the presence of renal dysfunction. In patients with ACS treated with a conservative ischemia-guided approach, low-molecular-weight heparin, unfractionated heparin, bivalirudin, or fondaparinux should administered as soon as possible unless there are significant contraindications. Patients managed with fondaparinux require an additional anticoagulant to prevent catheter thrombosis if a PCI is subsequently performed. Unfractionated heparin is continued for at least 48 hours, and enoxaparin or fondaparinux for the duration of the hospital stay (up to 8 days) in patients managed with medical therapy or until PCI is performed. If an early invasive strategy is planned, unfractionated heparin, enoxaparin, or bivalirudin should be initiated as soon as possible. Serial platelet counts are required to monitor for heparin-induced thrombocytopenia (HIT). Argatroban is an alternative anticoagulant in patients with known HIT. Patients who are adequately anticoagulated with warfarin still require antiplatelet therapy, but anticoagulation with heparin or alternative agents is generally not needed unless the international normalized ratio is less than 2.0.

4. Reperfusion Interventions

Fibrinolytic agents have no proven efficacy in NSTE-ACS. Patients with NSTE-ACS and shock benefit from early reperfusion with PCI or coronary artery bypass graft and should be triaged to the catheterization laboratory as soon as possible. An early invasive approach is clearly indicated in patients who have hemodynamic or electric instability, or refractory angina, and who lack serious comorbidities such as bleeding, advanced liver or renal failure, or end-stage disease such that the risk of PCI outweighs the benefit.

In other patients with NSTE-ACS, risk stratification is the key to the decision about an invasive strategy; cardiology consultation is usually warranted to help with the decision. An initial strategy of medical management with attempts at stabilization is warranted in patients with lower risk, but patients at higher risk should be considered for cardiac catheterization. Calculation of a GRACE risk score can be helpful with respect to timing; patients with a score > 140 benefited from early revascularization (< 24 hours) in the Timing of Intervention in Acute Coronary Syndromes (TIMACS) trial.

5. Other Interventions

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An echocardiogram should be part of the workup in ACS.

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High-dose statins are indicated for all patients with ACS. Echocardiography should be performed to evaluate LV performance because an angiotensin-converting enzyme (ACE) inhibitor or angiotensin receptor blocker should be administered to patients with NSTE-ACS and evidence of pulmonary congestion or LV ejection fraction < 40% unless contraindications are present. Aldosterone antagonist is an option in patients receiving an ACE inhibitor and β-blocker who have an ejection fraction < 40%, diabetes mellitus or heart failure, and no contraindications. Risk factor modification, including exercise, weight reduction, and smoking cessation, is recommended for all patients with ACS. Patients should be evaluated for diabetes mellitus even if not previously diagnosed.

III. ST-ELEVATION MYOCARDIAL INFARCTION

Patients with STEMI usually have plaque rupture with an occlusive coronary thrombus, resulting in a wave front of myocardial necrosis that begins at the endocardial surface within 15 minutes. The infarction progresses outward to the epicardium over approximately 6 hours unless collateral flow, spontaneous reperfusion, or reperfusion via an intervention is established. This progression may be modulated by the extent of collateral flow and determinants of myocardial oxygen consumption, which affords an opportunity for myocardial salvage. As with the patient with NSTE-ACS, prompt diagnosis and early treatment of the patient with STEMI is vital to optimize outcomes.

A. Diagnosis

Patients with STEMI typically present with prolonged chest pain and associated symptoms, but some patients have MIs that are painless (silent infarction/ischemia) or have other related symptoms, such as dyspnea and fatigue. In the critically ill patient population, STEMIs may not be associated with classic symptoms and are often suspected when complications occur, new arrhythmias develop, or ECG changes are noted. The physical examination findings are nonspecific.

The most common finding in patients with normal sinus rhythm is the S4 heart sound, indicating decreased left ventricular compliance at the end of ventricular filling. Bibasilar crackles as a result of pulmonary edema may be present and are helpful in assessing hemodynamic status. A brief focused physical examination aids in the diagnosis and assessment of possible complications of STEMI. A limited neurologic examination for evidence of prior stroke or cognitive deficits also should be conducted.

When possible, a prehospital 12-lead ECG should be obtained and interpreted to facilitate diagnosis, triage, and treatment on arrival at the medical facility. Otherwise, a patient with chest discomfort or symptoms suggestive of ACS should have this ECG performed and read within 10 minutes of arrival or detection of symptoms. The ECG is diagnostic of STEMI in the absence of QRS confounders (ie, bundle branch block, pacing, LV hypertrophy, Wolff-Parkinson-White syndrome) if it shows ≥ 2 mm of ST-segment elevation in two or more contiguous leads in men or ≥ 1.5 mm of ST-segment elevation in women in leads V_2-V_3 and/or ≥ 1 mm in other contiguous leads (**Figure 15-4**).

Patients with ECG findings of new or undiagnosed left bundle branch block and chest pain compatible with myocardial ischemia are treated similarly to those patients with ST-segment elevation. If the initial ECG is not diagnostic but the patient remains symptomatic with a high clinical suspicion for ischemia, serial ECGs at 5- to 10-minute intervals may be performed to detect the development of ST-segment elevation. A right-sided ECG showing ST elevation in right-sided V leads may suggest right ventricular infarction is present.

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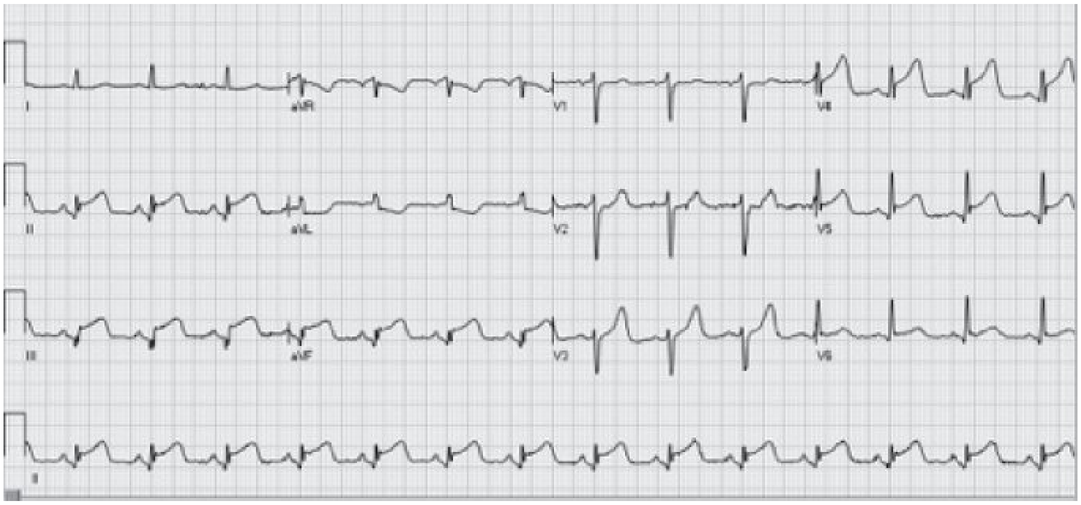
Cardiac catheterization in STEMI should not be delayed waiting for troponin results.

!

If the diagnosis is in doubt, echocardiography may add helpful information by showing focal wall motion abnormalities. The diagnosis is confirmed by elevated serum levels of cardiac-specific troponin, but reperfusion should not be delayed or deferred pending troponin levels.

Figure 15-4. ECG Indicating an Inferolateral STEMI



This electrocardiogram (ECG) shows classic findings of ST elevation in the inferior (II, III, and aVF) and lateral (V_4, V_5, V_6) leads, indicating an inferolateral ST-elevation myocardial infarction (STEMI).

B. General Management

Once STEMI is suspected or diagnosed, the immediate concerns are to ensure hemodynamic stability and to limit infarct size by restoring blood flow to the affected artery as soon as possible (**Figure 15-5**). Cardiology expertise should be sought promptly. Treatment of STEMI in the patient with other critical illness requires careful individualization. Absolute and relative contraindications to therapies must be considered and relative risk assessed. Choices may be limited by significant comorbidities, bleeding risk, the availability of specialized procedures, and the underlying prognosis.

1. Early Therapy

Immediate 12-lead ECG, cardiac-specific troponin measurement, and related laboratory tests should be completed. Aspirin should be administered immediately, and supplemental oxygen should be given in the presence of dyspnea, hypoxemia, heart failure, or shock.

Early restoration of flow in the infarct-related coronary artery is associated with improved survival in patients with STEMI; therefore, some type of reperfusion should be chosen as soon as possible. Primary PCI with stent placement is the preferred method if it can be performed quickly by experienced personnel; patients should be transferred directly to the catheterization laboratory in preference to other intensive care units when this is feasible. The door-to-balloon time goal is 90 minutes, but 60 minutes is preferable. Recent studies suggest that first medical contact to balloon time is a more relevant measure, with a goal set at 90 minutes. Activating the catheterization laboratory by obtaining and transmitting a prehospital ECG and taking appropriate patients directly to PCI-capable centers are strategies that can reduce time to revascularization.

The addition of a loading dose and subsequent maintenance doses of clopidogrel or ticagrelor as part of dual antiplatelet therapy may improve outcomes prior to PCI for STEMI, but consultation with the cardiology team is advisable because other options, such as short-acting intravenous platelet inhibition, may be advisable in some situations, especially if surgical intervention may be needed. An anticoagulant agent, unfractionated heparin or bivalirudin, should also be administered to patients undergoing PCI. Intravenous nitroglycerin may be useful in patients with STEMI and ongoing chest pain, hypertension, or heart failure, unless the systolic blood pressure is below 90 mm Hg. Intravenous β-blockers are not routinely administered but may be considered at presentation if hypertension or ongoing ischemia is present and there are no contraindications.

2. Acute Reperfusion Therapy

A plan for early reperfusion in patients with STEMI should be developed based on the resources available in the facility and community.

a. Percutaneous Coronary Intervention (PCI)

PCI involves deployment of an intracoronary drug-eluting stent, along with pharmacologic measures to prevent thrombosis. Primary PCI results in higher patency rates of the infarct-related coronary artery and lower rates of recurrent ischemia, reinfarction, and death. Primary PCI is the preferred reperfusion technique if the procedure can be performed by experienced personnel within 90 minutes of hospital presentation being preferred with clinical or electrocardiographic evidence of ongoing ischemia, even if more than 12 hours have elapsed since symptom onset.

If primary PCI is not available, and transfer to a facility with invasive reperfusion capability can be accomplished within 30 minutes, for a door-to-balloon time of less than 120 minutes, then this is the preferable option. If this is not an option because of logistic or other challenges, then fibrinolytic therapy is recommended, and this should be initiated within 30 minutes of hospital presentation.

Potential complications of an invasive strategy for treating STEMI include problems with the arterial access site, dye allergy, contrast nephropathy, complications of antithrombotic medications, technical complications, and reperfusion events.

Recent data indicate that a radial artery approach for primary PCI reduces major bleeding and access site complications and is associated with improved outcomes. This may shift the risk-benefit calculation in some patients prone to bleeding complications.

b. Fibrinolysis

If PCI is not available or cannot be performed within 120 minutes of arrival, fibrinolytic therapy should be considered. Limitation of infarct size is optimized when fibrinolytics are administered within 6 hours of symptom onset. The physician must weigh the potential risks against the benefits of fibrinolysis for each patient. If the decision to proceed is made and no absolute contraindications exist (**Table 15-6**), fibrinolytic therapy should be administered expeditiously. Several agents are available, including alteplase, reteplase, and tenectaplase, and all are effective. Doses are listed in **Table 15-7**. Findings that suggest reperfusion include relief of symptoms, maintenance or restoration of hemodynamic and/or electrical stability, and reduction of at least 50% of the initial ST-segment elevation injury pattern on a follow-up ECG performed 60 to 90 minutes after the initiation of therapy.

After fibrinolysis with a plasminogen activator, heparin should be used to maintain vessel patency for at least 48 hours. Aspirin should be continued.

Routine use of PCI in the first 2 to 3 hours after fibrinolytic therapy ("facilitated angioplasty") is not recommended.

Table 15-6 Contraindications for Fibrinolytic Therapy

Absolute Contraindications

- Prior intracranial hemorrhage
- Known cerebral vascular lesion
- Ischemic stroke within past 3 months
- Allergy to the agent
- Significant head or facial trauma within past 3 months
- Known intracranial neoplasm
- Suspected aortic dissection
- Active internal bleeding or bleeding diathesis (except menstruation)
- Intracranial or intraspinal surgery within past 2 months
- Severe uncontrolled hypertension (unresponsive to urgent therapy)

Relative Contraindications

- Severe uncontrolled hypertension on presentation (blood pressure >180/110 mm Hg)
- History of chronic, severe, poorly controlled hypertension
- Ischemic stroke >3 months ago or intracerebral pathology
- Current use of oral anticoagulants
- Traumatic or prolonged (>10 min) cardiopulmonary resuscitation
- Major surgery within past 3 weeks
- Previous use of streptokinase/anistreplase: allergy or prior exposure (>5 days ago)
- Active peptic ulcer disease
- Recent internal bleeding (within past 2–4 weeks)
- Noncompressible arterial or central venous puncture
- Pregnancy

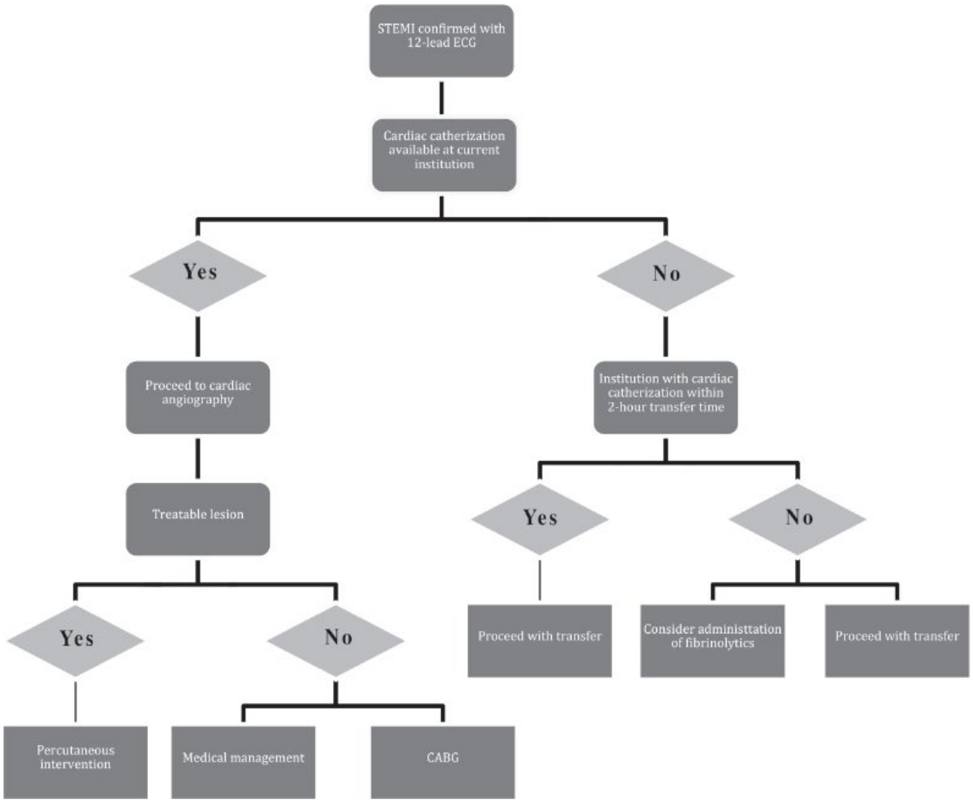
Table 15-7 Fibrinolytic Agents Used in ST-Elevation Myocardial Infarction

Streptokinase	1.5 million units intravenously over 30-60 min
Alteplase	15 mg intravenous bolus, then 0.75 mg/kg (maximum 50 mg) intravenously over 30 min, then 0.50 mg/kg (maximum 35 mg) intravenously over 60 min
Reteplase	10 units intravenously over 2 min followed in 30 min by 10 units intravenously over 2 min
Tenecteplase	Intravenous bolus adjusted for weight (30 mg if <60 kg; 35 mg if 60-70 kg; 40 mg if 70-80 kg; 45 mg if 80-90 kg; 50 mg if >90 kg)

> !
>
> *Time to open the infarct-related coronary artery is the most important determining factor when choosing options for reperfusion.*
>
> !

STEMI patients who develop cardiogenic shock or severe heart failure, or who have evidence of reperfusion failure or re-occlusion after fibrinolytic therapy, should be transferred to PCI-capable facilities as soon as possible. Patients with STEMI who are hemodynamically stable and achieve successful reperfusion also should be considered for transfer to a PCI-capable facility. Antiplatelet and anticoagulant therapy is continued after fibrinolysis and before transfer. The algorithm for triage and transfer of patients for reperfusion therapy in STEMI is found in **Figure 15-5**. For specific American Heart Association guidelines, see https://professional.heart.org/en/guidelines-and-statements.

Figure 15-5. Reperfusion Therapy for Patients with STEMI


STEMI confirmed with 12-lead ECG
Cardiac catherization available at current institution
Yes
No
Proceed to cardiac angiography
Institution with cardiac catherization within 2-hour transfer time
Treatable lesion
Yes
No
Proceed with transfer
Consider administtation of fibrinolytics
Proceed with transfer
Yes
No
Percutaneous intervention
Medical management
CABG

c. Coronary Artery Bypass Graft (CABG) Surgery in Patients with STEMI

Subsets of patients who present with STEMI may be better served with CABG. Patients with failed PCI or whose coronary anatomy is not amenable to PCI but who have ongoing symptoms of ischemia, cardiogenic shock, severe heart failure, or other high-risk features should be considered for CABG. CABG is also recommended in patients who require not only revascularization but also repair of a mechanical defect such as ventricular septal defect, free wall rupture, or papillary muscle rupture. The previously reported increased mortality in CABG patients who recently had a STEMI, and the increased bleeding in patients given recent dual antiplatelet therapy needs to be balanced against the need for revascularization.

PCI is not contraindicated by the presence of coma or a need for targeted temperature management after cardiac arrest.

3. Adjunctive Therapy

a. Antiplatelet Therapy

Dual antiplatelet therapy with aspirin and $P2Y_{12}$ inhibition is given to all patients undergoing PCI, as described previously. However, data suggest that even patients not undergoing PCI benefit from the addition of clopidogrel or ticagrelor to aspirin.

Ideally, thrombolytic therapy should be initiated within 30 minutes of the patient's arrival to the hospital.

Glycoprotein IIb/IIIa receptor antagonists inhibit the final common pathway of platelet aggregation, blocking crosslinking of activated platelets, but in the era of dual antiplatelet therapy, the role of addition of a glycoprotein IIb/IIIa inhibitor in primary angioplasty for STEMI is uncertain. "Upstream" (prior to PCI) use of GP IIb/IIIa receptor antagonists has failed to show benefit and is no longer recommended. They may be considered on an individual patient basis, if a patient has a large thrombus burden at PCI or if there was insufficient loading with a $P2Y_{12}$ receptor antagonist.

b. Anticoagulant Therapy

> *If PCI is not possible within 120 minutes, then fibrinolysis should be considered.*
>
> !

After fibrinolysis with a plasminogen activator, heparin should be used to maintain vessel patency for 48 hours, adjusted to keep the partial thromboplastin time at 1.5 to 2 times the control value. Heparin anticoagulation after use of streptokinase is not necessary. Patients who have intramural thrombus detected or suspected on echocardiography should receive heparin, and heparin should be considered in patients with large anterior infarctions who do not receive PCI or fibrinolysis.

c. β-Blockers

β-blockers are beneficial both in the early management of MI and as long-term therapy. Oral β-blockers should be initiated after the patient with STEMI has stabilized, ideally in the first 24 hours. Long-term use of these agents is helpful in all patients who are at risk for recurrent cardiovascular events and who have no contraindications to their use.

d. Renin-Angiotensin System Inhibitors

Inhibitors of angiotensin-converting enzyme (ACE) decrease circulating angiotensin II levels and increase levels of bradykinin, which in turn stimulates production of nitric oxide. ACE inhibitors have been shown to improve hemodynamics, functional capacity, and symptoms. They also improve survival in patients with chronic congestive heart failure and prevent the development of congestive heart failure in patients with asymptomatic LV dysfunction. Patients treated with ACE inhibitors after MI showed improved survival, with particular benefit in patients with LV dysfunction (ejection fraction $< 40\%$), anterior infarction, or pulmonary congestion. This improved survival was additive to the benefits of aspirin and ß-blockers. The mechanisms responsible for the benefits of ACE inhibitors most likely include limitation in the progressive LV dysfunction and enlargement (remodeling) that often occur after infarction, but a reduction in ischemic events was also seen. Immediate intravenous ACE inhibition with enalaprilat has not been shown to be beneficial, but oral ACE inhibition should be started early in the hospital course. An ACE-I should be administered within the first 24 hours to all patients with STEMI and LV dysfunction or heart failure unless hypotension (systolic blood pressure < 100 mm Hg) or other contraindications, most prominently a history of angioedema, are present. Baseline renal function should be taken into consideration when initiating an ACE inhibitor or an angiotensin receptor blocker (ARB), but renal failure is not an absolute contraindication to their use. Patients should be started on low doses of oral agents and titrated to maximally tolerated doses. STEMI patients that are intolerant to an ACE-I should be given an ARB. ARBs have been shown to be non-inferior to ACE inhibitors in this setting.

e. Statins

Multiple studies have shown that statin use in patients after ACS can prevent death, recurrent MI, and stroke. Use of a high-intensity statin is preferred and should be initiated before discharge. In patients with ACS, high-intensity statin therapy should be given regardless of the LDL level. Contraindications to statin use include a history of statin-induced rhabdomyolysis or significant myopathy and/or acute liver injury, but often patients who did not tolerate one statin will tolerate another.

f. Calcium Channel Blockers

Long-acting calcium channel blockers may be a useful secondary therapy for recurrent myocardial ischemia but are not appropriate for first-line treatment. Randomized clinical trials have not demonstrated that routine use of calcium channel blockers improves survival after MI. Immediate-release nifedipine is contraindicated in the treatment of an acute MI. Diltiazem and verapamil are contraindicated in patients with STEMI and LV dysfunction and heart failure.

Transfer to a facility providing a higher level of care is indicated for patients who have persistent ischemic symptoms after MI, who develop cardiogenic shock, who have heart failure despite aggressive therapy, or who have recurrent ventricular fibrillation or tachycardia despite aggressive antiarrhythmic therapy.

C. Complications

Common early complications of MI are heart failure and cardiogenic shock, recurrent ischemia and/or infarction, and arrhythmias. Urgent cardiology consultation should be obtained as soon as possible to assist with management and decisions regarding advanced interventions in all patients with complications of ACS.

1. Heart Failure and Cardiogenic Shock

Heart failure after ACS generally results from LV pump failure. Echocardiography should be performed to evaluate LV function and to rule out mechanical complications, and expert consultation should be sought. Consideration should be given to evaluation for residual ischemia or restenosis or thrombosis of a recently placed stent.

Pharmacologic treatment of heart failure should be tailored to the patient's clinical and hemodynamic state. Clinical evaluation can assess perfusion and intravascular volume by characterizing patients as wet or dry and warm or cold, but hemodynamic monitoring can be useful, especially if patients do not respond promptly to empiric therapy because clinical assessment of cardiac output is difficult unless patients are in frank shock. Patients with a systolic arterial pressure >100 mm Hg and low cardiac output should be treated initially with a vasodilator, usually IV nitroglycerin (doses of 0.3 to 1 μg/kg/min, titrated up in increments of 0.5 μg/kg/min every 10 minutes). If arterial pressure decreases or cardiac output remains inadequate, inotropic support with dobutamine may be initiated (5 μg/kg/min) and titrated as needed. Milrinone is an alternative inotropic agent with less arrhythmogenic effect than dobutamine, although it is often associated with hypotension. In countries where it is available, levosimendan has shown favorable inotropic and hemodynamic benefits, although improved outcomes have not been demonstrated in cardiogenic shock. Intravenous loop diuretics, such as furosemide and bumetanide should be used to reduce pulmonary congestion. Hypotension is rarely attributable to diuretic-induced hypovolemia in this setting.

Cardiogenic shock represents the leading cause of in-hospital death after MI. Cardiogenic shock is diagnosed clinically by hypoperfusion and hypervolemia (wet and cold) and hemodynamically by persistent hypotension with reduced cardiac index. Cardiac dysfunction in patients with cardiogenic shock is usually initiated by MI or ischemia, which can then be exacerbated by hypotension. Compensatory mechanisms that retain fluid in an attempt to maintain cardiac output may add to the vicious cycle and further increase diastolic filling pressures. The interruption of this cycle of myocardial dysfunction and ischemia forms the basis for the therapeutic regimens for cardiogenic shock. Early recognition of cardiogenic shock and timely management with revascularization is paramount to improve outcomes.

Echocardiography provides information about overall and regional systolic function, diastolic function, and valvular disease, and can rapidly diagnose mechanical causes of shock. Right-heart catheterization is useful to characterize hemodynamics and to optimize therapy in unstable patients in whom clinical estimates of filling pressures can be unreliable, and optimal filling pressures may be higher than expected in those with LV diastolic dysfunction. Concomitant right ventricular dysfunction is often underrecognized in patients with cardiogenic shock, and its importance is underappreciated; right-heart catheterization is the best and most expeditious way to assess right-sided hemodynamics and its response to therapy in these patients. Measurement of cardiac output and mixed venous saturation can speak to the adequacy of cardiac performance and help select patients for inotropic and or mechanical circulatory support.

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> *Cardiogenic shock in the setting of acute MI is an indication for emergent revascularization (either percutaneous intervention or coronary artery bypass grafting).*
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Prompt revascularization is the only intervention that consistently reduces mortality rates in patients with cardiogenic shock. In a randomized trial of patients with LV failure complicating STEMI, coronary revascularization with PCI or CABG within 48 hours of presentation reduced all-cause mortality compared with optimal medical management. As such, urgent cardiac catheterization, with transfer to a PCI-capable institution if needed, is warranted in patients with cardiogenic shock.

Therapy with vasopressor agents may be required to maintain coronary perfusion pressure, to break the vicious cycle of progressive hypotension with further myocardial ischemia. Norepinephrine is the preferred first-line agent in this setting. Inotropic agents, such as dobutamine, may be added to raise cardiac output as a supporting measure.

Percutaneous Mechanical Circulatory Support

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Percutaneous mechanical circulatory support should be considered in patients with ACS and shock or impending shock, based on hemodynamic assessment.

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Percutaneous mechanical circulatory support devices can increase arterial pressure and cardiac output, reduce LV filling pressures and afterload, and support coronary perfusion. They can provide short-term support as a bridge to recovery or to transplantation. Mechanical therapy may be preferable to vasoactive agents in this regard because those agents can increase myocardial oxygen demand and decrease microvascular flow. Choices include intra-aortic balloon pumping, implantable centrifugal pump, the axial flow pump, and extracorporeal membrane oxygenation. A key issue in choosing among mechanical support options is right ventricular function; some patients with both right- and left-heart failure might benefit from initial biventricular support with the addition of right ventricular support. Invasively derived parameters that have been shown to be useful in selecting among mechanical support devices include the cardiac power index (CO × MAP/456) an index of LV contractile function, and pulmonary artery pulsatility index (PAPI: pulmonary artery pulse pressure/right atrial pressure). Trials have not shown that an intra-aortic balloon pump can improve outcomes in patients with cardiogenic shock. Percutaneous left ventricular assist devices provide better hemodynamics compared with the intra-aortic balloon pump, with higher cardiac indices and mean arterial pressures as well as lower filling pressures, but they have not been shown to improve mortality.

2. Right Ventricular Infarction

Right ventricular infarction results in elevation of right atrial and right ventricular filling pressures and low cardiac output. These hemodynamic abnormalities result in characteristic clinical findings of hypotension, clear lung fields, and distended internal jugular veins. The ECG usually reveals an inferior infarction, and an ECG tracing of the right precordial leads should be obtained and may reveal ST-segment elevation, especially in V_4R. Initial therapy includes maintenance of right ventricular preload with volume expansion until the blood pressure is stabilized. Associated bradycardia or high-degree heart block may require chemical or electrical intervention. Agents that reduce preload should be avoided, such as morphine, nitrates, ACE inhibitors/angiotensin receptor blockers, and diuretics. If volume expansion is inadequate to stabilize the patient, inotropic support with dobutamine should be considered.

3. Mechanical Complications

Mechanical complications following MI include ventricular free wall rupture, ventricular septal rupture, and acute mitral regurgitation, all of which typically occur during the first week after infarction.

Ventricular free wall rupture is often lethal although its incidence is low ($< 1\%$). Risk factors include the absence of collateral flow, anterior location of the infarct, use of corticosteroids or nonsteroidal anti-inflammatory agents, age > 70 years, and female sex. Pseudoaneurysm with leakage may be heralded by chest pain, nausea, and restlessness, but frank free wall rupture presents as a catastrophic event with shock and electromechanical dissociation. Echocardiography reveals pericardial effusion, and salvage is only possible following prompt recognition and thoracotomy for repair.

Ventricular septal rupture presents as hypotension, severe biventricular heart failure, and cardiogenic shock with physical findings of a pansystolic murmur and parasternal thrill. The hallmark finding is a left-to-right intracardiac shunt (“step-up” in oxygen saturation from right atrium to right ventricle), but the diagnosis is most easily made with echocardiography. Rapid institution of supportive pharmacologic measures and mechanical support is necessary. Surgical repair is the only viable option for long-term survival, but even if done in a timely manner, mortality remains high, ranging from 20% to 80%.

Ischemic mitral regurgitation may be seen following an inferior MI because of compromised blood flow to the posterior papillary muscle. The typical presentation is that of acute-onset pulmonary edema and cardiogenic shock. The murmur of acute mitral regurgitation may be limited to early systole because of rapid equalization of pressures in the left atrium and left ventricle or may be soft or inaudible when cardiac output is low. Diagnosis is made by echocardiography. Afterload reduction inotropic or vasopressor therapy may temporize by supporting cardiac output and blood pressure, but definitive therapy is surgical valve repair or replacement, which should be undertaken as soon as possible because clinical deterioration can be sudden.

4. Recurrent Ischemia or Infarction

Recurrent ischemia or infarction occurs in up to 20% of patients treated with fibrinolytic therapy for MI, whereas patients receiving primary PCI have a lower incidence of recurrent ischemia. Ischemia after MI can be caused by residual stenosis in the infarct-related artery, by disease in another coronary artery, or by occlusion of a new stent. An ECG recorded during recurrent pain should be compared with those from the index MI event. Reinfarction may be difficult to diagnose because cardiac troponins are unreliable since levels can be elevated for 5 to 14 days and because the ECG may be evolving. If there is high suspicion for reinfarction, cardiac catheterization should be considered regardless of cardiac biomarker values or ECG findings. Nonischemic etiologies, such as pericarditis and pulmonary embolism, should also be considered as potential causes of recurrent chest pain.

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Detection of reinfarction is clinically important because it carries incremental risk for the patient.

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Treatment of post-MI ischemia is similar to management of the initial MI but also includes cardiac catheterization and reperfusion, if possible. Acute reperfusion with PCI or coronary artery bypass graft may be required for stabilization.

3. Arrhythmias

Arrhythmias associated with ACS and reperfusion include atrial bradycardias, atrial tachycardias, atrioventricular (AV) blocks, ventricular tachyarrhythmias, and asystole. Hemodynamically significant atrial bradycardia or AV block in the setting of inferior MI can be treated initially with IV atropine in a dose of 0.5 mg every 3–5 minutes to a total dose of 3 mg while preparing for transcutaneous pacing. Atropine rarely corrects complete heart block or type II second-degree AV block, especially when this occurs in the course of an anterior MI. Temporary transvenous pacing is indicated for complete heart block, bilateral bundle branch block, new or indeterminate-age bifascicular block with first-degree AV block, type II second-degree AV block, and symptomatic sinus bradycardia that is unresponsive to atropine. Transcutaneous pacing should be initiated for patients who have indications for emergent temporary pacing until transvenous pacing can be instituted.

Acute onset of chest pain, dysrhythmias, or pulmonary edema – shortly after PCI – should raise concern for acute occlusion of a new stent.

Atrial tachycardias, such as atrial fibrillation, may cause hemodynamic instability and precipitate myocardial ischemia, or they may be clinically insignificant and transient. Immediate cardioversion is indicated in unstable patients. Depending on the specific arrhythmia, IV adenosine, β-blockers, diltiazem, digoxin, or amiodarone may be effective. Careful attention must be given to contraindications for any of these agents.

Ventricular tachycardia and ventricular fibrillation should be treated according to current advanced cardiac life support guidelines. After defibrillation and if indicated, amiodarone is the drug of choice in patients with an acute MI. Antiarrhythmic drugs are not recommended as prophylaxis for ventricular arrhythmias in the setting of acute MI. To aid in the prevention of postinfarction arrhythmias, prompt recognition and correction of systemic precipitants (including hypoxemia, acid-base abnormalities, and electrolyte disturbances) is recommended.

D. Special Considerations

1. Perioperative MI

Perioperative MI can occur before surgery, intraoperatively, and during the postoperative period. The last is the most common, with the peak incidence on the third postoperative day. Perioperative MI is often associated with atypical presentations and may be painless; patients rarely experience classic symptoms and signs of acute coronary syndromes, or symptoms may be masked by analgesics and/or sedatives. New-onset or increased atrial or ventricular arrhythmia is often the presenting finding, as is postoperative pulmonary edema. Other possible presentations may include hemodynamic instability and respiratory distress. The diagnosis can be sometimes confirmed with serial ECG and cardiac marker determinations, but echocardiography can be particularly useful to identify new wall motion abnormalities in cases with diagnostic uncertainty. Medical therapy to decrease myocardial oxygen demand is usually the first line of therapy.

Catheterization with potential PCI should be considered as long as dual antiplatelet therapy is feasible; fibrinolytic therapy is often contraindicated.

2. Effects of Coexisting Diseases

Many critically ill patients have more than one medical condition that may require significant alterations in the standard therapeutic approach. Some have relative or absolute contraindications to standard medications or procedures. Patients with stress ulceration or gastritis may not be candidates for aspirin therapy. Postoperative patients or those with a bleeding diathesis may not be candidates for clopidogrel, heparin, fibrinolytic therapy, or aspirin. β-blockers should be avoided in patients with significant ongoing bronchospasm or decompensated heart failure. Many drugs will need dose adjustments for renal or hepatic dysfunction. Critical illness of a non-cardiac origin may result in decreased oxygen delivery to the myocardium and subsequent myocardial dysfunction. Recommended management of multiple organ failure in critical illness focuses on supportive care and treatment of the underlying disease.

3. Targeted Temperature Management After Cardiac Arrest

Neurologic injury is the most common cause of death in patients with out-of-hospital cardiac arrest. Patients who do not follow commands or have purposeful movements should receive targeted temperature management. Lowering the core body temperature to between 32°C and 36°C (89.6°F and 96.8°F) for 24 hours after cardiac arrest with appropriate supportive care can improve neurologic outcome. Targeted temperature management is associated with an increased risk of coagulopathy and infection.

Key Points

Acute Coronary Syndromes

- The preliminary diagnosis of NSTE-ACS is based on the clinical symptoms, assessment of risk factors for coronary artery disease, and ECG interpretation.
- A 12-lead ECG should be obtained and interpreted within 10 minutes in patients with possible ACS.

- For patients with suspected NSTE-ACS, perform risk stratification, select an initial management strategy, complete the diagnostic evaluation, and use medical therapy and revascularization as appropriate.
- Non–enteric-coated aspirin at a dose of 162 to 325 mg should be administered (and chewed) as soon as possible in all patients with suspected or diagnosed ACS.
- Antiplatelet and anticoagulant agents are important interventions in all patients with ACS.
- High-risk patients (continuing ischemia, elevated troponin levels) with NSTE-ACS may be candidates for additional therapy with an early invasive strategy.
- Oral β-blockers should be initiated in the first 24 hours for all patients with ACS unless strong contraindications are present.
- A plan for early reperfusion of patients with STEMI should be developed based on resources available in the facility and community.
- Primary PCI is the preferred reperfusion technique if it can be performed expeditiously by experienced personnel. Fibrinolytic therapy for reperfusion in STEMI ideally should be initiated within 30 minutes of the patient's arrival to the hospital if timely PCI cannot be performed.
- All patients with acute MI, whether they undergo reperfusion therapy or not, should be treated with aspirin and another antiplatelet agent, such as clopidogrel, prasugrel, or ticagrelor.
- Use of ACE inhibitors decreases the mortality rate in patients with STEMI.
- PCI is not contraindicated in patients with coma or a need for targeted temperature management after cardiac arrest.
- Patients with cardiogenic shock in the setting of acute MI should undergo emergent revascularization.

Suggested Readings

1. Albanez B, James S, Agewall S, et al. 2017 ESC Guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation: The Task Force for the management of acute myocardial infarction in patients presenting with ST-segment elevation of the European Society of Cardiology (ESC). *Eur Heart J*. 2018;39: 119-177.

2. Amsterdam EA, Wenger NA, Brindis RG, et al. 2014 ACC/AHA guideline for the management of patients with non-ST-elevation acute coronary syndromes: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2014;130(25):2354-2394.

3. Hollenberg SM. Myocardial ischemia. In: Hall J, Schmidt G, Kress J. *Principles of Critical Care*. 4th ed. New York, NY: McGraw-Hill Education; 2015:1108-1151.

4. Nikolaou NI, Welsford M, Beygui F, et al. Part 5: Acute coronary syndromes: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. *Resuscitation*. 2015;95:e121-e146.

5. O'Gara PT, Kushner FG, Ascheim DD, et al. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *Circulation* 2013;127(4):e362-e425.

6. Roffi M, Patrono C, Collet JP, et al. 2015 ESC guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation. Task Force for the Management of Acute Coronary Syndromes in Patients Presenting without Persistent ST-Segment Elevation of the European Society of Cardiology (ESC). *Eur Heart J*. 2016;37(3):267-315.

7. Thygesen K, Alpert JS, Jaffe AS, et al. Fourth universal definition of myocardial infarction (2018). *J Am Coll Cardiol*. 2018;72(18):2231-2264.

Suggested Websites

1. American College of Cardiology. http://www.acc.org.
2. American Heart Association. http://www.americanheart.org.
3. European Society of Cardiology. http://www.escardio.org.
4. Global Registry of Acute Cardiac Events (GRACE). http://www.outcomes-umassmed.org/GRACE/default.aspx.
5. National Institute for Health and Clinical Excellence. http://www.nice.org.uk.
6. Thrombolysis Myocardial Infarction (TIMI) Study Group. http://www.timi.org.

Chapter 16

CARDIOVASCULAR SURGICAL EMERGENCIES

✓ Objectives

- Identify patients who have issues with bleeding after cardiovascular surgical (CVS) procedures including coronary artery bypass graft (CABG) procedures, percutaneous coronary interventions (PCI), or percutaneous arterial interventions.
- Outline basic management and interpretation of information, output, character, and quantity from chest tubes placed for purposes of CABG.
- Identify signs, symptoms, and therapeutic options for patients with suspected cardiac tamponade status post CABG.
- Identify signs, symptoms, and therapeutic options for patients with suspected complications from insertion of intravascular sheaths/lines/devices employed during the performance of cardiovascular surgical procedures.
- Identify signs, symptoms, and therapeutic options for patients with a pulseless extremity.
- Identify signs, symptoms, and therapeutic options for patients with vasoplegia.

Case Study

A 66-year-old man has recently returned from the operating room after a CABG procedure performed immediately after an emergent cardiac catheterization for unstable angina. He has a 40-pack per year smoking history, poorly controlled type 2 diabetes mellitus, endogenous obesity, a body mass index (BMI) of 35, hypertension, and gout. He arrives to the ICU paralyzed, intubated, and ventilated through a 7.5 outer diameter endotracheal tube (OD ETT), 23 cm from the lip, on the following settings: assist control volume ventilation with a rate of 16, tidal volume of 500 mL, FIO_2 of 0.80, and positive end-expiratory pressure (PEEP) of 5 cm H_20. He has a heart rate of 80 beats/min sinus rhythm, and is not currently paced but has both atrial and ventricular pacemaker wires attached to a pacemaker generator. His temperature is 36°C (96.8°F), blood pressure is a mean arterial pressure (MAP) of 65 mm Hg per a right radial arterial line, and there is a pulmonary artery catheter (PAC) in place via the right internal jugular site with good waveforms with readings of pulmonary artery pressure (PAP) of 32/14 mm Hg. He has two peripheral 20-gauge IVs placed in each extremity. A 30 French left chest tube and two 30 French mediastinal tubes are all connected to separate enclosed suction systems at –20 cm H_20 suction. He has an intact sternal dressing as well as a 7.5 French right femoral artery sheath which had been placed emergently in the cardiac catheterization suite prior to surgery.

- What additional information is needed to determine whether the postoperative course will be uneventful?
- What possible events may contribute to the morbidity or mortality of a procedure performed for cardiovascular disease?

I. INTRODUCTION

It is estimated that, one in four deaths are attributable to cardiovascular disease (CVD) in the United States of America. This represented approximately 660,000 new deaths and over 300,000 new coronary attacks. CVD is the impetus leading to the performance of over seven million inpatient procedures, which represented approximately 14% of all United States medical costs in 2013 valued at an estimated $316 billion dollars (Benjamin et al., 2017). Worldwide, CVD remains the most common factor underlying death (**Table 16-1**).

Table 16-1 Significant Events Which May Contribute to the Morbidity or Mortality of a CVD-Related Procedure

- History of medications used pre- and perioperatively
- History of allergies
- Details of procedure:
  - Number of grafts
  - Aortic cross-clamp time
    - Condition of native aorta (atherosclerotic or soft)
  - Total pump time
  - Details of weaning from cardiopulmonary bypass (CPB)
  - Blood loss from drains since transport from the operating room

Data taken from Despotis GM, et al.[6]

Every surgical procedure has an intrinsic risk or inherent risk of morbidity or mortality. The CABG procedure carries an overall mortality of about 3%. This number includes elective, emergent, and true emergency procedures. It is estimated that purely elective procedures have been reported to have a lower mortality approximating 1.7%.

Risk factors for complications after a CABG procedure for CVD include:

1. Older age > 70 years

2. Small size body
3. Prolonged CPB time
4. Increased numbers of distal anastomoses
5. Use of the internal mammary artery as a conduit for bypassing diseased coronary vessels
6. Lower preoperative platelet counts
7. Lower body temperature post procedure, postoperative infusion of lower intravenous volumes for fluid overload
8. Higher positive end-expiratory pressure (PEEP) during mechanical ventilation postoperatively
9. Higher volumes of transfusion of blood products
10. Use of perioperative antiplatelet therapies, such as aspirin, and/or P2Y12 inhibitors such as clopidogrel, prasugrel, ticagrelor, cangrelor, or ticlopidine (**Table 16-2**).

Table 16-2 Patient- and Procedural-Associated Risk Factors for Post CABG Bleeding

Patient- or preprocedure-related risk factors	**Procedure-related risk factors**
Older age	Prolonged CPB times
Low preoperative platelet counts	Infusion of lower temperature intravenous volumes
Smaller body size < 25 Kg/m^2 (generally female sex)	Increased numbers of distal anastomoses or the use of the internal mammary artery as a conduit for bypassing diseased coronary vessels
Lower body temperature post pump run	Higher PEEP during mechanical ventilation
	Perioperative antiplatelet therapies (ie, aspirin and or P2Y12 inhibitors, clopidogrel, prasugrel, ticagrelor, cangrelor, or ticlopidine)
	High volume of blood products transfused during the procedure

Abbreviations: CABG, coronary artery bypass graft surgery; CPB, cardiopulmonary bypass; PEEP, positive end-expiratory pressure

Significant events which may contribute to the morbidity or mortality of a CVD-related procedure are the history of medications used pre- and perioperatively; medication allergies; procedural details: number of grafts, aortic cross-clamp time, condition of native aorta (atherosclerotic or soft), total pump time, details of weaning from CPB, and blood loss from drains since transport from the operating room.

Many procedures related to CVD are invasive, frequently involve access to venous or arterial systems, and can be accompanied by bleeding. It is estimated that the incidence of bleeding as a complication of a CVD procedure ranges from 2% to 7%. If bleeding accompanies a CVD procedure, it may account for a two-to fourfold increase in overall procedural mortality. It is important to recall that patients who have had the need for a cardiovascular procedure are at risk for subsequent cardiovascular events including cerebrovascular accident (CVA), myocardial infarction (MI), congestive heart failure (CHF), and sudden death by nature of their underlying disease process and comorbidities.

The performance of procedures to correct CVD are not infrequently fraught with unique associated complications that may or may not involve bleeding but are directly related to:

- The procedure itself
- The use of modalities employed to support the patient through the perioperative period
- Conditions that may arise independently of the cardiac procedure

It is important to recall that patients who have had the need for a cardiovascular procedure are at risk for subsequent cardiovascular events including cerebrovascular accident (CVA), myocardial infarction (MI), congestive heart failure (CHF), and sudden death by nature of their underlying disease process and comorbidities.

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II. IDENTIFICATION OF PATIENTS AT RISK FOR BLEEDING AFTER A CARDIOVASCULAR SURGICAL PROCEDURE

One of the most common and dramatic postoperative events after a cardiovascular surgical procedure is bleeding. The bleeding may be minor, only requiring simple interventions such as transfusion or may necessitate surgical reoperation in as many as 3% to 5% of all patients. Ideally the identification of bleeding should begin with identification of the potential for bleeding. This identification should be considered in all patients before it occurs in the majority of cases. The classification of postoperative bleeding is a complex issue. An overriding principle that must be applied is that as a caregiver's concerns for bleeding arise, it is mandatory that it is communicated to all members of the team, including the operating surgeon. If bleeding occurs and is unchecked, unrecognized, or underappreciated, it is associated with a wide spectrum of events ranging from blood loss anemia, hemodynamic instability, ventilation compromise, pericardial tamponade, and sudden cardiac arrest. Bleeding in the post CVS patient may be subtle or catastrophic. It may be heralded by increases in blood from the surgical sites, venipuncture sites, and surgical drains or from the gastrointestinal tract as a result of direct intestinal ischemia from low flow states, embolic phenomena, or preexisting gastrointestinal disease. As previously described, various patient and procedural factors have been associated with the appearance of post CVS bleeding. Some factors are generic to the physiology of coagulation, or patient-specific, and others are procedural-specific. Patient-associated events and some procedural-related events are described in **Table 16-2**.

> *One of the most common and dramatic postoperative events after a cardiovascular surgical procedure is bleeding. The bleeding may be minor, only requiring simple interventions such as transfusion, or may necessitate surgical reoperation in as many as 3% to 5% of all patients.*

Risk factors that can be potentially modified are the restoration of body temperature, judicious use of intravenous fluids, blood products, and mechanical ventilation settings. Reversal of procedural anticoagulation may involve the use of protamine sulfate. Dosages of protamine used in reversal of heparin should be evaluated compared with intraoperative dosages administered, adjusted for time since administration, and checked for inaccuracies in timing or dose to avoid attempts to reverse heparin that has already been metabolized. One milligram of protamine neutralizes approximately 100 units of heparin. After 2 hours of the last heparin dose, the protamine dose should be decreased by half. Protamine is generally given to neutralize heparin. If protamine is administered unopposed or in doses above what is required, it is by itself an anticoagulant unless bound to heparin.

Additional defects in coagulation should be identified. Recently the platelet and its unique task in regulating the thrombin switch has been recognized as holding a central position in the regulation of coagulation. Although some patients may present with isolated congenital disorders of bleeding, the more common scenario observed in bleeding is from a medication-related issue that produces an acquired defect in platelets. Procedural issues related to bleeding or the consequences of ongoing bleeding and resultant depletion of clotting system factors may also contribute to the aggravation of postoperative bleeding.

Bleeding is usually not due to a single coagulation derangement but appears that most patients undergo a progressive series of sequential effects to their coagulation system which, in aggregate, creates bleeding.

Bleeding is usually not due to a single coagulation derangement but appears that most patients undergo a progressive series of sequential effects to their coagulation system which, in aggregate, creates bleeding. Coagulation defects acquired with extracorporeal circulation are divided into alterations of the overall numbers of platelets, defects in platelet functionality from medications and pump effects (generally related to reduction of coagulation factors or pump washout), and reduction in levels of fibrinogen. See **Table 16-3** for sources and prevalence of hemostatic defects in cardiac surgery and its integration into a diagnostic framework.

Table 16-3 Sources of Hemostatic Defects in Cardiac Surgery

Hereditary coagulation defect vs acquired defects after cardiac surgery	**Source of defect**	**Therapeutic interventions**
Hereditary Platelet Disorders	Abnormal adhesion or aggregation receptors, storage defects	Platelet transfusions One apheresis pack = six random-donor platelet units and will raise counts by 30–60,000 platelets per μL
	Mild bleeding (storage pool defects, signal transduction defects)	Platelet transfusions
	Severe bleeding (ie, as related to adhesion or aggregation defects)	Institution-based MTP
Coagulation factor deficiency		
	Factor VII	FFP or CRYppt *
	Factor VIII	FFP or CRYppt *
	Factor IX	FFP or CRYppt *
	Factor XI	FFP or CRYppt *
	Factor V, X	FFP or CRYppt *
	afibrinogenemia,	FFP or CRYppt *
	dysfibrinogenemia	FFP or CRYppt * or 15–30 U per kg recombinant
	Factor XIII	Factor XIIIa
	Factor II (prothrombin deficiency)	FFP or CRYppt
	von Willebrand disease (75% Type 1)	FFP or CRYppt * alternately desmopressin (DDAVP) or uremia-induced platelet dysfunction or hereditary platelet disorders, Type 1 von Willebrand disease 0.3–0.4 μg per kg over 30 min. May cause hypotension *(15 mL per kg of fresh frozen plasma/10 U per kg CRYppt) will raise fibrinogen by ≈ 50–100 mg per dL unless factor-specific concentrates are available
Acquired with extracorporeal circulation **(PUMP-ASSOCIATED)**		
Thrombocytopenia Qualitative platelet abnormalities		
Thrombocytopenia	<50,000 platelets per μL and ACTIVE bleeding <100,000 platelets per μL and ACTIVE bleeding	Platelet transfusions One apheresis pack = six random-donor platelet units and will raise counts by 30–60,000 platelets per μL
Qualitative platelet abnormalities	Reduced TRAP-mediated activation in PRP Reduced PAF-mediated activation in whole blood	Platelet transfusions One apheresis pack = six random-donor platelet units and will raise counts by 30–60,000 platelets per μL
	Coagulation factor deficiency (<20% activity)	15 mL/kg of fresh frozen plasma/10 U CRYppt
	Hypofibrinogenemia (fibrinogen < 100 mg/dL)	15 mL/kg of fresh frozen plasma/10 U CRYppt

Abbreviations: CRYppt, cryoprecipitate; FFP, fresh frozen plasma; MTP, massive transfusion protocol; PAF, platelet-activating factor; PRP, platelet-rich plasma; TRAP, thrombin receptor agonist peptide

Data taken from Despotis GM, et al.[6]

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Careful review of preoperative medications as well as knowledge of modalities and/or specific reversal agents are useful to address certain bleeding events before a series of procedural-related factors render the patient coagulopathic. Administration of platelets, provision of blood products, and specific coagulation factors to support patient-related factors should be planned ideally with the guidance of a vascular medicine consultant or hematologist.

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Acquired platelet defects from inborn disorders of metabolism or specific genetic conditions have been described. Careful review of preoperative medications as well as knowledge of modalities and/or specific reversal agents are useful to address certain bleeding events before a series of procedural-related factors render the patient coagulopathic. Administration of platelets, provision of blood products, and specific coagulation factors to support patient-related factors should be planned, ideally with the guidance of a vascular medicine consultant or hematologist (**Table 16-4**).

A. Identification of Bleeding

Close monitoring of chest tube initial output is imperative following any cardiovascular invasive procedures. Early identification of a patient who is bleeding allows for early intervention to decrease the potential for further adverse events. Mediastinal and pleural chest tubes are placed at the completion of surgical procedures requiring opening of the thoracic cavity. The Birmingham Criteria describe management decisions based on interpretation of information, output, character, and quantity from chest tubes which had been placed at the time of CABG, or an additional cardiac procedure such as valve replacement/repair. These criteria facilitate the decisions surrounding timing of a patient's return to the operating room for bleeding or other catastrophic event. The criteria are based on a time-related set of volumes taken from termination of the operating room event through the postoperative period. The criteria are based on volume of bleeding from chest drainage tubes considered against the time to accumulate the drainage. Trigger points may vary from large volumes over a short period of time to lesser volumes over a longer period of time.

Generally, the five criteria that have been described are:

!

Close monitoring of chest tube initial output is imperative following any cardiovascular invasive procedures.

!

1) The range of volumes over a given time period, specifically a drainage of more than 500 mL for the first hour after surgery, more than 400 mL per hour for the 2 hours following surgery, more than 300 mL per hour for the first 3 hours after surgery, or more than 1000 mL TOTAL in the first 4 hours after surgery

2) The development of any sudden massive bleeding at any time

3) Obvious signs of cardiac tamponade

4) Excessive bleeding which does not reach volume triggers but leads to coagulopathy or difficulty in maintaining coagulation state

5) Cardiac arrest postoperatively (**Table 16-5**)

Table 16-4 Available Reversal Agents for Oral Anticoagulants and Suggested Use

Reversal agent	Vitamin K antagonists (warfarin)	Factor IIa inhibitor (dabigatran)	Factor Xa inhibitors (apixaban, edoxaban, and rivaroxaban)
4F-PCC (56)	First line	Second line	First line
aPCC	Not indicated	Second line	Second line
Idarucizumab	Not indicated	First line	Not indicated
Andexanet	Not indicated	Not indicated	First line
Plasma (FFP)	4-PCC or aPCC	Not indicated	Second line
Vitamin K	2.5–10 mg IVP over 20 minutes is indicated with 4-PCC, aPCC or FFP.		

Abbreviations: 4F-PCC, 4-factor prothrombin complex concentrate; aPCC, activated prothrombin complex concentrate

Reprinted from *J Am Coll Cardiol*, 70(24), Tomaselli GF, et al., 2017 ACC Expert Consensus Decision Pathway on Management of Bleeding in Patients on Oral Anticoagulants: A Report of the American College of Cardiology Task Force on Expert Consensus Decision Pathways, 3042-3067, Copyright (2017), with permission from Elsevier.

Table 16-5 Indications for Re-exploration after CVS

Volume of chest tube drainage	Time in hours post-surgery
More than or equal to (≥) 500 mL	First hour post-surgery
≥ 400 mL per hour	First 2 hours following surgery
≥ 300 mL per hour	First 3 hours after surgery
≥ 1000 mL total	First 4 hours after surgery
Any sudden massive bleeding at any time	Any time after surgery
Obvious signs of cardiac tamponade	Any time after surgery
Excessive bleeding which does not reach volume triggers but leads to coagulopathy or difficulty in maintaining coagulation state	Any time after surgery
A cardiac arrest postoperatively	Any time after surgery

Data taken from JW Kirklin, 1986 and Karthik et al., 2004.

B. Chest Tubes Management

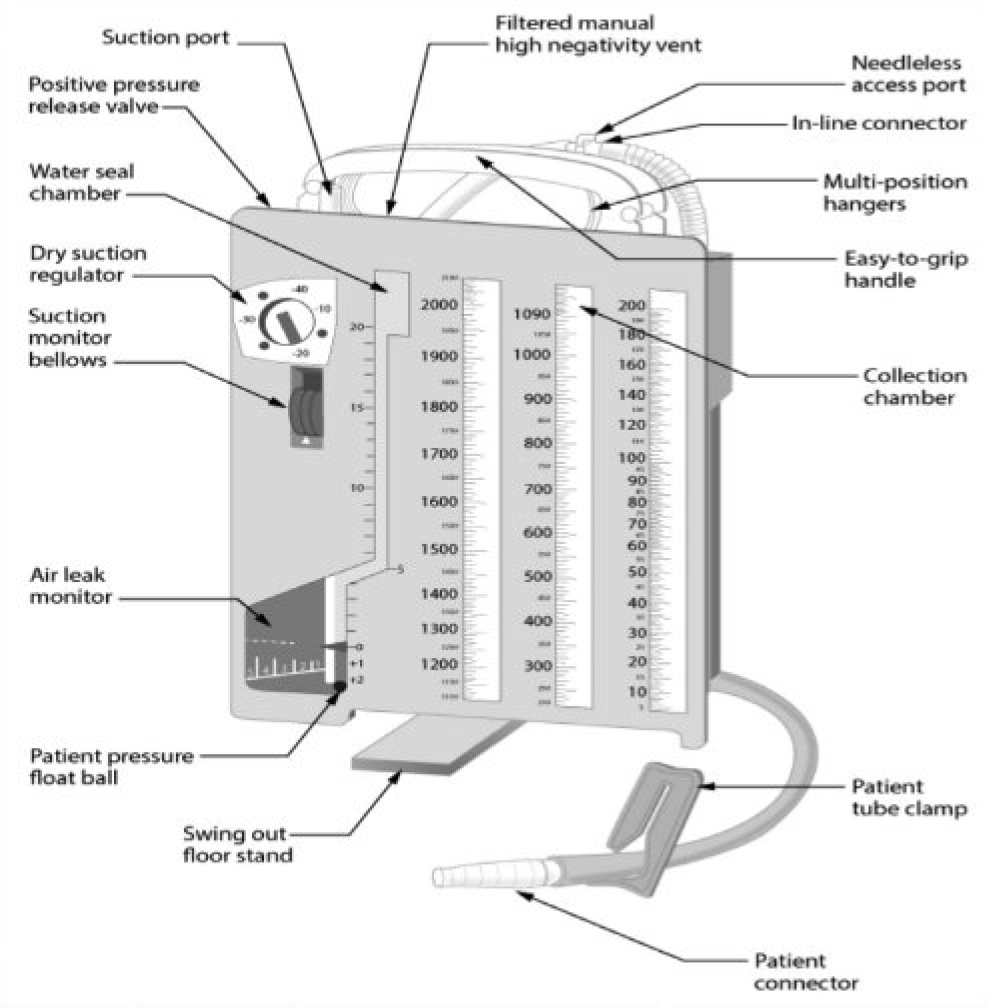
!

Evaluation of chest tubes should include the mnemonic DOPA (Drainage, Output, Position, Air leak).

!

Following initial placement, chest tubes, mediastinal and/or pleural, should be placed to continuous wall suction moderated to achieve a desired level usually around −20 to −40 H_2O. Evaluation of chest tubes should include the mnemonic DOPA (**D**rainage, **O**utput, **P**osition, **A**ir leak). The consistency and color as well as the amount of drainage should be evaluated and documented. Monitoring the drainage system for air leaks should be done by bedside providers at least hourly. Air leaks are present if bubbling occurs in the water seal chamber of the drainage system. If a continuous air leak is present, inspect the tubing and connections from the skin to the device to assess their integrity to rule out a mechanical problem rather than a primary patient source. The amount of drainage, color, consistency, and presence of air leak all need to be evaluated prior to consideration of removal of a chest tube. Drainage should be consistent with serosanguineous or serous drainage. The amount of drainage should be approximately 20 mL/hr for the 8–12 hours prior to removal. If an air leak is present, a chest tube should not be removed until the air leak has resolved or the cause is identified and corrected. Providers should become familiar with the system used at their institution (**Figure 16-1**).

Figure 16-1. Chest Drainage System


Suction port
Filtered manual high negativity vent
Needleless access port
Positive pressure release valve
In-line connector
Water seal chamber
Multi-position hangers
Dry suction regulator
Easy-to-grip handle
Suction monitor bellows
Collection chamber
Air leak monitor
Patient pressure float ball
Swing out floor stand
Patient tube clamp
Patient connector

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C. Management of Coagulation Defects and Postoperative Bleeding

Most defects in coagulation can be addressed by the appropriate transfusion of either fresh frozen plasma or cryoprecipitate concentrates. In certain situations, factor-specific concentrates are available as well as specific antidote reversal agents for medications. Earlier guidelines for administration of blood products and coagulation factors for cardiac surgery have been published by the National Institute of Health (NIH) as well as the American Association of Anesthesiologists.

> *Most defects in coagulation can be addressed by the appropriate transfusion of either fresh frozen plasma (FFP) or cryoprecipitate concentrates.*

In general, an infusion of 15 mL/kg of fresh frozen plasma (FFP) will raise levels of most factor levels to $>30\%$ activity, which is sufficient for correction of the most commonly encountered defects. Cryoprecipitate is reserved when hypofibrinogenemia (80 to 100 mg/dL) or states of dysfibrinogenemia related to consumption is present. Approximately 10 international units (IU) of cryoprecipitate will increase fibrinogen levels by 50–100 mg/dL and is thought to be equivalent to the increased volume represented by 15 mL/kg doses of FFP. Infusion of specific factor concentrates at rates outlined in **Table 16-3** can occur every 12 to 24 hours. The administration of platelets is guided by the symptomatology of the patient. Platelets may be infused for patients with active bleeding and a platelet count of less than 50,000 platelets per μL, or if there are questions as to the functional capacity of the platelets which may have been rendered abnormal from administration of medications to maintain patency of stents or intravascular devices. In non-bleeding patients, platelet administration is generally unnecessary to prevent risk of isosensitization without regard to specific platelet counts. Rarely, after the administration of chemotherapeutic agents which may render platelets poorly functional, prophylactic platelet infusions are necessary but not until counts drop below 20,000 platelets per μL. In cases of massive blood loss, generally defined as greater than one or two blood volumes, expert opinion suggests initiation of a massive transfusion protocol (MTP) and blood products transfused in a 1:1:1 or 1:1:2 ratio of packed red blood cells (PRBCs):FFP:platelets. Specific medication interactions and newer reversal agents for novel anticoagulants are found in **Table 16-4**. Current recommendations by the American College of Cardiology expert opinion panel downplay the utility of FFP in favor of novel prothrombin complex concentrates (PCC). Sometimes there is a need for a hematology consult to assist in management.

> *In cases of massive blood loss, generally defined as greater than one or two blood volumes, expert opinion suggests initiation of a massive transfusion protocol (MTP) and blood products transfused in a 1:1:1 or 1:1:2 ratio of PRBCs:FFP:platelets.*

Other interventions can be used to help control postoperative bleeding, especially venous bleeding. Increasing the PEEP on the ventilator theoretically should increase the intrathoracic pressure, thus causing tamponade of the venous bleeding. However, increased pleural pressures have been known to increase the risk of bleeding and therefore, careful assessment of the patient must occur prior to trying this intervention. Hypertension in cardiac surgery patients should be controlled with a goal of a systolic blood pressure < 140 to prevent venous bleeding during the initial postoperative period. Specific patient populations may benefit from desmopressin (DDAVP) administration such as patients who received aspirin within 7 days of surgery, patients with CPB times exceeding 140 minutes, and patients with demonstrable preor perioperative platelet dysfunction. DDAVP is an option for a patient with uremia in acute or chronic kidney dysfunction.

III. CARDIAC TAMPONADE

Cardiac tamponade exists when fluid within or around the pericardial space exists, compresses, and compromises the compliance of the heart chambers, which prevents normal filling and produces a picture of obstructive shock. Cardiac tamponade may arise from medical diseases and may have a rapid or gradual onset. It can be caused by cancer, renal failure, chest trauma, pericarditis, connective tissues diseases, hypothyroidism, tuberculosis, and aortic rupture. When it occurs after CVS, it is one of the most serious complications of cardiac surgery and the presentation is usually acute. Symptoms include shortness of breath (if not ventilated), generalized weakness, lightheadedness, and cough. It is a diagnosis primarily based on clinical suspicion and the findings of hypotension, jugular venous distension, muffled or quiet heart sounds, or a new pericardial rub. A pulsus paradoxus, defined as a greater than 10 mm Hg difference in systolic blood pressures taken at end expiration versus full inspiration, can occur. The pathophysiology of cardiac tamponade can present as Beck's triad, which is the combination of hypotension, distended neck veins, and distant, muffled heart sounds. One, some, or all of these symptoms may be present with cardiac tamponade. A high suspicion for tamponade is based on history and presence of symptoms.

The diagnosis of tamponade can be suggested by specific electrocardiogram (ECG) changes revealing low voltage or a chest radiograph that demonstrates a flask-shaped heart shadow. Bedside ultrasound reveals a characteristic appearance of fluid within the pericardial sac. When tamponade presents in patients who have preexisting hemodynamic monitoring, a hallmark finding is the equalization of right and left heart pressures. Equalization of cardiac right-sided diastolic pressures with a reduction of left-sided heart pressures is the most frequently observed pattern. This pattern is detected when invasive monitoring lines, such as a pulmonary artery catheter (PAC)and arterial line, are in place.

The severity of symptoms is dependent on the rate of fluid accumulation within or adjacent to the heart. The pericardium of the heart is a discrete anatomic space which usually contains 15–50 mL of fluid. If excess fluid accumulates slowly, as in a chronic cancer patient, the normal pericardium can stretch allowing it to accommodate up to 2 liters with relatively few symptoms. A more rapid rise of 150–200 mL of fluid typically is seen in the postoperative period and will produce a progressive reduction in diastolic ventricular filling with reductions in stroke volume and cardiac output. Despite the presence of drainage catheters in the pleural and mediastinal spaces in the postoperative cardiac patient, blood may accumulate and cause tamponade physiology.

A. Treatment

Generally, tamponade occurring early in the postoperative course of a cardiac surgery patient is best managed with a prompt return to the operating room with reopening of the original sternotomy or thoracotomy.

Some post-operative patients have the pericardium left unapproximated. Despite the open nature of the pericardium, tamponade may occur. Percutaneous maneuvers, such as catheter drainage and performance of subxiphoid windows, have been described as a means of treatment in both acute and more chronic presentations. Generally, tamponade occurring early in the postoperative course of a cardiac surgery patient is best managed with a prompt return to the operating room with reopening of the original sternotomy or thoracotomy. Post operative cardiac tamponade occurs in 3% to 5% of cardiac surgery patients. A pattern of early abatement of bleeding from chest drains, followed by signs of hemodynamic compromise (tachycardia, narrowing of pulse pressure, oliguria, and acidosis increases in inotrope support) generally occurs. Echocardiography, which is helpful in more chronic conditions of slowly accumulating tamponade, may not provide sufficient information in this setting related to spectral interference from drains, sternal wires, and obscuring of windows due to dressings or monitor devices. Transesophageal echocardiography (TEE) is an alternative option to view the pericardial fluid collection, cardiac chambers, and myocardial contractility. Open drainage is preferred because collections of fluid may be heterogeneous and contain both liquid and clotted blood. The collections may be located posterior to the heart which further limits echocardiographic visualization or percutaneous attempts at drainage. An additional value of open drainage is that it allows direct visualization of potential sites of bleeding.

A return to the operating room for bleeding is not without consequences. In several series, a return to the operating room and reopening of either a thoracotomy or sternotomy has been associated with increased rates of:

- Perioperative stroke
- Perioperative renal injury coupled with the need for postoperative dialysis
- Prolonged mechanical ventilation (>72 hours)
- The need for postoperative mechanical circulation support with assist devices
- A fourfold increase in sternal wound infections
- A threefold increase in pulmonary infections
- Prolonged stays in the ICU

It is not surprising that a return to the operating room portends a nearly three-time greater mortality rate than those patients who did not return to the operating room for evaluation of suspected tamponade or bleeding.

Open drainage has been reported to be successful, with overall salvage rates that range from as low as 50% of patients in early case series to as high as 90% of patients in more recent case series. Time to return to the operating room is an important factor with a delay in return as a frequently cited factor in mortality. Re-exploration is associated with an increased risk of sternal infection in up to 2% of patients who undergo reoperation.

IV. COMPLICATIONS FROM INSERTION OF INTRAVASCULAR SHEATHS/LINES/DEVICES FOR CARDIAC SURGERY

Vascular access related to cardiac surgery ranges from simple peripheral intravenous devices to large-diameter sheaths capable of providing a portal for insertion of additional hemodynamic monitors, circulatory assist devices, or use of CPB support. Complications from the insertion of percutaneously inserted devices may include infection, hemorrhage, thrombosis, hemolysis, and damage to adjacent structures. Complications related to insertion of intravascular sheaths/lines/devices for cardiac surgery may be of minor consequence or may lead to death.

Of the implantable devices, central venous catheters (CVCs), single or multi-luminal, are the most common. It has been estimated that in the United States there are approximately 15 million CVC days per year. It is estimated that as many as two-thirds of all ICU patients have a CVC at some point in the continuum of their care.

A. Infections

Infectious complications may arise secondary to a break in aseptic technique during insertion, faulty technique in the use of catheters, hematogenous seeding of catheters from abscess sites distant to the catheter, or increased duration of use, generally related to failure to promptly remove devices that have outlived their useful period of use. Current recommendations to minimize the risks of infection are:

- The practice of appropriate hand hygiene before insertion and before manipulation of catheters
- The employment of full head-to-toe barriers with cap, mask, sterile gowns, and gloves for insertion
- The use of chlorhexidine-based skin disinfectant with the added caveat of allowing full drying of the agent before insertion

- Avoidance of sites prone to infection, such as the femoral site

The site of CVC insertion has been related to the presence of infectious complications with the risk decreasing in the order of site of insertion: subclavian (SCV) < jugular (IJV) < femoral (FV). The use of ultrasound guidance is the standard of care and should be used to aid insertion of CVC when available. Peripherally inserted central catheters (PICCs) appear to have a similar risk of infection to CVC lines in several series, emphasizing the principle of prompt removal of unnecessary devices. Aseptic techniques when accessing central lines, as well as prompt removal of unused devices and avoiding routine site rotation or routine line guidewire changes of existing lines, are believed to reduce the incidence of device-related infection.

> *Infectious complications may arise secondary to a break in aseptic technique during insertion, faulty technique in the use of catheters, hematogenous seeding of catheters from abscess sites distant to the catheter, or increased duration of use, generally related to failure to promptly remove devices that have outlived their useful period of use.*

A frequently employed device in cardiac surgery is the pulmonary artery Swan-Ganz catheter. Recent reviews suggest that complications secondary to mispositioning, misinterpretation of waveforms, potential for creation of structural damage to the heart, knotting, infection, fragmentation, malignant dysrhythmias, pulmonary infarction, and rupture of the pulmonary artery are all factors that may limit the use of this device.

B. Hemorrhage

Retroperitoneal hemorrhage is an infrequent occurrence with a rate of less than 1% yet it is a serious complication following transfemoral access catheterization procedures with a mortality of 7%. Survival from retroperitoneal hemorrhage depends on prompt diagnosis and appropriate management. The clinical presentation of retroperitoneal hemorrhage may vary, which sometimes can lead to delayed diagnosis, hemodynamic instability, or unrecognized compartment syndrome. Factors related to catheter-related retroperitoneal hemorrhage include:

- Access above the inguinal ligament
- Puncture or through and through needle arterial access leading to vessel disruption
- Avulsion or blind advancement of guidewire/sheath into small arterial side branches

The three main management strategies are conservative medical management, percutaneous endovascular intervention, or surgical vascular surgery intervention. Conservative medical management includes volume resuscitation with isotonic fluid, serial determinations of hemoglobin/hematocrit, and transfusion of blood products as needed. If the patient becomes hemodynamically unstable, has signs or symptoms of shock, or worsening acidosis or coagulopathy escalation for percutaneous endovascular intervention or vascular surgery, consultation is needed.

With advancements in technology, complications with the use of larger size arterial catheters and sheaths are dependent on the size of the device relative to the size of the arterial vessel insertion site. Devices with larger diameters are more likely to reduce or occlude distal flow in vessels, if:

- Placed in smaller diameter vessels
- Vessels are affected with peripheral vascular disease
- Patients are of smaller stature

!

> *Factors related to catheter-related retroperitoneal hemorrhage include access above the inguinal ligament, puncture or through and through needle arterial access leading to vessel disruption, and avulsion or blind advancement of a guidewire/sheath into small arterial side branches.*
>
> !

Intra-aortic balloon pumps (IABP), temporary ventricular assist devices, or veno-arterial extracorporeal membrane oxygenation (ECMO) may result in the development of distal ischemia, embolization, tissue loss, or permanent nerve injury. A well-documented complication of an IABP is the development of a foot drop from peroneal nerve palsy in survivors.

C. Treatment

Treatment is best directed at prevention of complications by appropriate training of individuals performing procedures. All procedures should involve documenting the risks and benefits and sharing anticipated outcomes with patients.

V. EARLY CARDIAC ARREST IN THE POSTOPERATIVE CARDIAC SURGERY PATIENT

A rare, but deadly serious complication in a postoperative cardiac surgery patient is cardiac arrest. Estimates of occurrence of cardiac arrest after cardiac surgery fall between 0.7% and 5.2% of all patients who undergo a cardiac operation. Most occur relatively early in the postoperative course, with 50% occurring in the first 3 hours and 84% in the first 8 hours following surgery. This would imply that most of these arrests are witnessed because all postoperative patients are closely monitored in an ICU setting with a trained team immediately available. In most cases, an exact etiology for the arrest is frequently not discovered due to the retrospective nature of investigations of arrests and the inherited limitations with such reviews. Most retrospective reviews have focused on the identification of a pre-arrest deterioration in physiology and stress the benefit of early recognition of potentially reversible etiologies prior to the arrest.

The correctible causes listed as precursors to arrest generally include:

- Malignant dysrhythmias
- Hemorrhage-induced hypovolemia
- Cardiac tamponade
- Hypoxia
- Electrolyte abnormalities
- Tension pneumothorax
- Failure of pacing devices or wires
- Ongoing graft occlusion ischemia

Ventricular fibrillation (VF) is the cause of 25% to 50% of arrests attributable to malignant dysrhythmias in the immediate postoperative period, with the next most common causes of arrests related to cardiac tamponade and major bleeding.

The actual figures for patient survival after a perioperative arrest is unknown. The reported range of survivors is from 5% to 70%. Most figures for survival after arrest approximate 50% whether the resuscitation occurs with an open or closed chest.

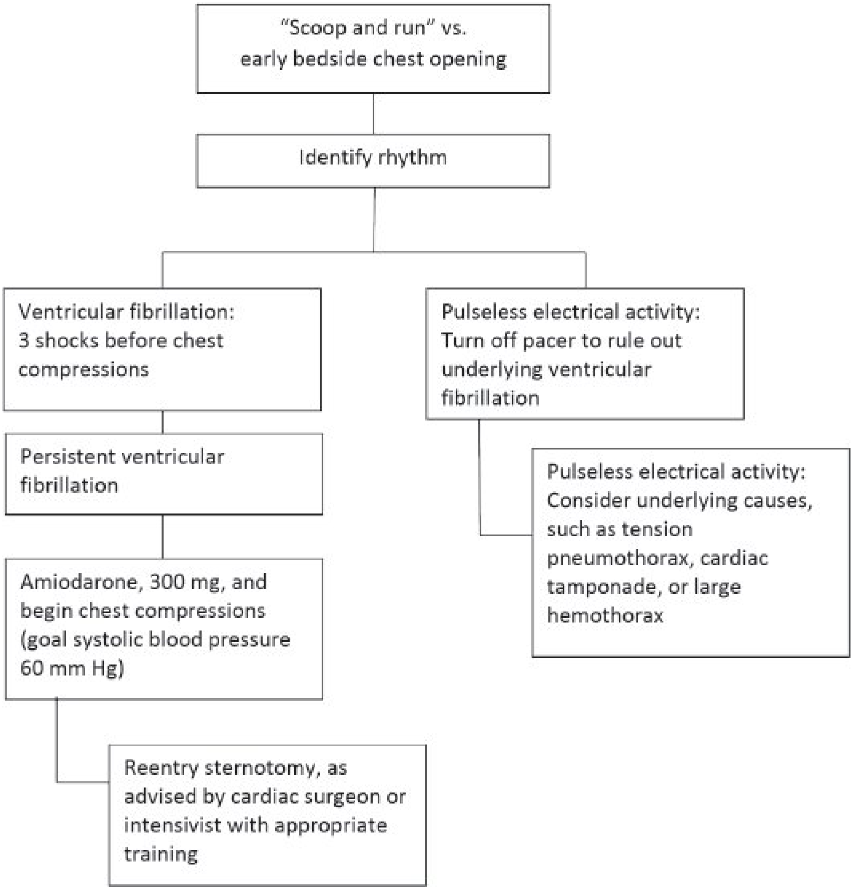
> *The correctible causes listed as precursors to arrest generally include malignant dysrhythmias, hemorrhage-induced hypovolemia, cardiac tamponade, hypoxia, electrolyte abnormalities,*

tension pneumothorax, failure of pacing devices or wires, and ongoing cardiac ischemia.

!

Early defibrillation without CPR, chest compressions coupled with defibrillation as needed, attempts at high-level pacing prior to performance of compressions, rapid opening of the chest at the bedside in the ICU, or "scoop and run" (rapid return to operating room) techniques (**Figure 16-2**) to allow opening of the chest in the operating room have all been suggested. Proponents of rapidly opening the chest propose early identification of correctable causes such as bleeding or tamponade which may be altered successfully. In the few reports that address this action, survivors of successful resuscitation are largely reported to be discharged neurologically intact.

Figure 16-2. Algorithmic Schema for Treatment of Early Postoperative Arrest


"Scoop and run" vs. early bedside chest opening
Identify rhythm
Ventricular fibrillation: 3 shocks before chest compressions
Persistent ventricular fibrillation
Amiodarone, 300 mg, and begin chest compressions (goal systolic blood pressure 60 mm Hg)
Reentry sternotomy, as advised by cardiac surgeon or intensivist with appropriate training
Pulseless electrical activity: Turn off pacer to rule out underlying ventricular fibrillation
Pulseless electrical activity: Consider underlying causes, such as tension pneumothorax, cardiac tamponade, or large hemothorax

A. Treatment

As mentioned previously, cardiac arrest in the postoperative cardiac surgery patient differs significantly from the typical out-of-hospital cardiac arrest scenario for which advanced cardiac life support (ACLS) was designed. Patients are in monitored conditions and have a wide spectrum of associated data, not the least of which are a complete history, frequent and concurrent laboratory values, and readily available resuscitative equipment. Although there is still controversy surrounding the proper treatment of cardiac arrest in the postoperative cardiac surgery patient, the Society of Thoracic Surgeons recently adopted an expert consensus statement advocating for early defibrillation, minimizing external CPR, and rapid reopening of the chest.

The first step in the treatment of the arrest is to identify the rhythm and determine whether it will respond to defibrillation. In the case of ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT), rapid defibrillation is the preferred treatment. It is generally believed that external CPR is not needed if defibrillation can be provided in less than 1 minute, a goal that should be generally obtainable in a modern ICU setting. Unlike traditional ACLS, defibrillation should proceed with three shocks before proceeding to external CPR. Studies have shown that this stacked shock strategy has improved Return of Spontaneous Circulation (ROSC), improved 24-hour survival, and improved survival to hospital discharge.

If the patient remains in VF/VT following three shocks, a bolus dose of 300 mg IVP amiodarone is recommended. This is consistent with ACLS guidelines. If VF/VT persists, it is unlikely that additional defibrillation will be effective and at this point, external CPR should begin as a bridge to re-entry sternotomy. External CPR is largely ineffective in cases of cardiac tamponade or bleeding, two of the more common causes of postoperative cardiac surgery arrest. This objective finding has led to the conclusion to withhold compressions prior to defibrillation, based on reports of myocardial injury, sternal and rib fractures, damage or avulsion of grafts, lung injury, disruption of implanted prosthetic valves, and hemorrhage caused by CPR which invokes the concept of “primum non nocere” (first, do no harm) in choosing the route to avoid potential complications. External CPR may be necessary, but should be performed cautiously, targeting a rate of 100–120 bpm and an SBP of 60 mm Hg on the arterial line.

The first step in the treatment of the arrest is to identify the rhythm and determine whether it will respond to defibrillation. In the case of ventricular fibrillation (VF) or pulseless

ventricular tachycardia (VT), rapid defibrillation is the preferred treatment.

Another unique quality of the postoperative cardiac surgery patient is the common presence of epicardial pacing wires. Most patients following cardiac surgery will have epicardial pacing wires placed before leaving the operating room and they will be connected to an external pacemaker device. In the case of patients with arrests arising from asystole or severe bradycardia, pacing via this device should be initiated immediately. If the patient does not have epicardial pacing wires in place or if they fail to work properly, external pacing should be attempted. As with VF/VT arrests, it is acceptable to delay external CPR for up to 1 minute in order to allow attempts to pace the heart. If pacing remains unsuccessful at this point, external CPR should be initiated, again as a bridge to re-entry sternotomy.

In cases of apparent pulseless electrical activity (PEA), and if the patient is being paced, the pacemaker should be turned off to ensure that the PEA is not actually an underlying VF/VF. Additional considerations, such as the presence of tension pneumothorax or large hemothorax, should be considered in PEA arrests. The position of the endotracheal tube should be confirmed to ensure that it has not been displaced.

In cases of apparent PEA, and if the patient is being paced, the pacemaker should be turned off to ensure that the PEA is not actually an underlying VF/VF. Additional considerations, such as the presence of tension pneumothorax or large hemothorax, should be considered in PEA arrests.

Administration of epinephrine is standard practice in ACLS. It is difficult to separate the effects of bolus epinephrine from continuous infusion of inotrope-vasopressors frequently used in the perioperative period. The Society of Thoracic Surgeons (STS) guidelines acknowledge, however, that epinephrine may be useful in smaller doses (50–300 mcg) in certain situations but cautions that it should only be given under the guidance of experienced clinicians and not as part of a protocol.

Re-entry sternotomy should ideally be performed by or under the guidance of a cardiac surgeon and definitive repair of cardiac defects causing arrest is beyond the scope of this course. However, immediate opening of the chest to evacuate cardiac tamponade or provide internal cardiac massage may be a life-saving temporizing measure until a cardiac surgeon is available. Current STS guidelines suggest that properly trained intensivists, including advanced practice providers, may safely perform the procedure in emergency situations. In general, postoperative arrests mirror that of nonoperative-associated arrests and guidelines stress prompt defibrillation and immediate uninterrupted high-quality chest compressions.

VI. THE PULSELESS EXTREMITY IN THE POSTOPERATIVE CARDIAC SURGERY PATIENT

Individuals with coronary artery disease (CAD) are frequently afflicted with peripheral arterial disease (PAD). The similarities in risk factors for CAD and PAD are mirrored with that for cerebrovascular disease. This association assumes a major role when interventions for CAD involve procedures that require canalization of extremity arterial supply for diagnostic or therapeutic purposes because insertion of support devices may produce undesired side effects including limb ischemia, cerebrovascular embolization, or bleeding. The pulseless extremity in the postoperative cardiac surgery patient is a surgical emergency and frequently associated with the need for additional interventions. Extremity vascular-related complications are not limited to the arterial system. Ischemic limb complications can be classified into those associated with a direct intervention in the afflicted limb such as the insertion of either a venous or arterial catheters and those in which a previously present or undisclosed insufficiency is unmasked by alterations in cardiac output or the use of vasopressor agents in the perioperative period.

The pulseless extremity in the postoperative cardiac surgery patient is a surgical emergency and frequently associated with the need for additional interventions. Extremity vascular-related complications are not limited to the arterial system.

Recent estimates of deep vein thrombosis (DVT) occurrence in the postoperative CABG patient range from 10% to 48% with an average value of 20%. The incidence of pulmonary embolus may be as high as 10% in this population and is thought to be related to reluctance of early anticoagulation use in the perioperative period, immobility imposed by monitoring, and ventilator assist devices as well as inflammatory changes produced by CPB itself. Venous complications may lead to short-term or long-term disability related to chronic venous insufficiency. A rare complication of venous thrombosis is phlegmasia cerulea dolens which, if untreated, can progress to venous gangrene of an extremity.

Arterial complications may present as a result of unresolved cardiogenic shock in the postoperative period or may be a result of the need for higher doses of vasopressors to sustain goals for mean arterial pressure. Arterial complications have a wide range of presentations and are reported to appear in 10% to 70% of patients who have varying degrees of shock, low flow, and/or require insertion of intravascular support devices such as IABP, ventricular support devices, or ECMO cannulae. Patients who develop complications after device insertion often have a high prevalence of historic risk factors generally associated with PAD and include preexisting hypertension, diabetes mellitus, hyperlipidemia, and smoking. Arterial insufficiency after CABG is associated with higher mortality. There is a disease-related effect, with an increased risk of mortality in those patients afflicted with diabetes mellitus versus the non-diabetic, 58% versus 34%.

It is felt that in addition to the presence of risk factors contributing to PVD already mentioned, size discrepancies of arteries with respect to the size of support catheters may have a role. When time permits, care should be taken to perform a thorough vascular examination prior to the contemplation of or insertion of cardiovascular support devices. The upper extremity is not immune to ischemia because brachial artery access has also been associated with distal vascular complications.

A. Treatment

Emphasis should be placed on obtaining an accurate pre-insertion history and conducting a physical examination with attention to documentation of a thorough neurologic examination and noting condition of the extremities prior to insertion of devices. Coordination of goals and expectations with all team members for hemodynamic variables, acceptable ranges of vasopressors, and vigilance in monitoring limb perfusion in sites of insertion of monitoring lines or assist devices will also reduce this complication.

The hallmarks of physical examination are often referred to as the six “Ps”: pain, paresthesia, pallor, pulselessness, paralysis, and the ominous appearance of poikilothermia. Once the complication of a pulseless limb occurs, the time to treatment is critical. Of the reported signs, paresthesia appears to be an early sign. Reliance on Doppler pulses or delay in consultation is dangerous. Misinterpretation of Doppler signals may give a false sense of security with signals appearing as a result of a water hammer-type phenomenon. Options for therapy include removal of the device, local anticoagulation or lytic therapy, or thrombectomy from either an urgent interventional radiographic or open vascular surgical consultation.

VII. VASOPLEGIA

Vasoplegia, a term resulting from the combination of the Latin root words vaso for vessel or container and plegia or stroke, is a syndrome characterized by a low mean arterial blood pressure and a high cardiac index in the face of adequate cardiac filling pressures. It has been described in a diverse spectrum of conditions including cardiac and non-cardiac surgery, sepsis, neuroaxial anesthesia, trauma, burns, and pancreatitis.

Vasoplegia is most commonly described as a complication of CPB, with a reported incidence of between 5% and 25%. It is characterized by significant hypotension, a mean arterial pressure < 60, normal or high cardiac outputs, and low systemic vascular resistance (SVR) despite treatment with fluids and vasopressors. Once the syndrome develops, afflicted patients are at increased risk for death and other major complications following cardiac surgery with mortality as high as 25% in those patients in whom the condition lasts longer than 48 hours postoperatively.

Multiple risk factors have been described that may predict vasoplegia in the postoperative cardiac patient (**Table 16-6**). The exact pathogenesis remains unclear but is thought to involve activation of the contact, coagulation, and complement systems with resultant activation of leukocytes, platelets, and endothelial cells. This causes release of intracellular contents including bradykinin and other substances affecting the vascular tone.

Table 16-6 Multiple Risk Factor Categories for Vasoplegia

Medications	Surgical Procedure	Disease States
• Angiotensin-converting enzyme inhibitors (ACE inhibitors) • Angiotensin-receptor blockers (ARBs) • Calcium channel blockers (CCBs) • Amiodarone • Beta-blockers • Unfractionated heparin	• Valvular procedures • Surgical procedures for CHF	• Anemia requiring PRBC transfusion • Ejection fraction < 35%

The treatment of vasoplegia relies primarily on recognition of its presence and the use of support in the form of vasopressors which exhibit primarily alpha-1 effects. If present, vasoplegia presents and is associated with hypotension, refractory to treatment, and mortality may be as high as 25%. The link to nitric oxide-related vasoactive substances has prompted treatment with methylene blue in order to reverse refractory hypotension, but at present conclusive evidence is lacking.

> *Vasoplegia is most commonly described as a complication of CPB, with a reported incidence of between 5% and 25%. It is characterized by significant hypotension, a mean arterial pressure < 60, normal or high cardiac outputs, and low systemic vascular resistance (SVR) despite treatment with fluids and vasopressors.*

Key Points

Cardiovascular Surgical Emergencies

- Coronary artery bypass grafting carries an overall mortality of about 3%, including elective, emergent, and true emergency procedures.
- Risk factors for complications after a CABG procedure could be patient- or procedure-dependent.
- Most patients who have postoperative bleeding sustain a progressive series of sequential hits to their coagulation system which, in aggregate, creates the bleeding.
- In general, most defects in coagulation can fortunately be addressed by the appropriate transfusion of either fresh frozen plasma or cryoprecipitate concentrates.

- Platelet administration is guided by the symptomatology and may be infused for patients with active bleeding and a platelet count greater than 50,000 platelets per μL or if there are questions as to the functional capacity of the platelets. In non-bleeding patients, platelet administration is generally unnecessary and rarely administered.

- In massive blood loss, initiate a massive transfusion protocol (MTP): transfuse in 1:1:1 or 1:1:2 ratio of PRBCs:FFP:platelets.

- Prothrombin complex concentrates (PCCs) may be used instead of FFP after consultation with experts in vascular medicine or hematology.

- Cardiac tamponade exists when fluid within or around the pericardial space exists and compresses and compromises the compliance of the heart chambers. This prevents normal filling and produces a picture of obstructive shock.

- Criteria for emergent re-exploration after CABG include increasing chest tube drainage, sudden massive bleeding, tamponade physiology signs, and cardiac arrest.

- The risks of intravascular device placement cannot be underestimated, and devices should be promptly removed at the earliest point in postoperative care.

- Vasoplegia is a syndrome characterized by a low mean arterial blood pressure and a high cardiac index in the face of adequate cardiac filling pressures. It is treated with fluids and vasopressor agents.

- In all instances in which consultation is requested, it is mandatory that communication to all members of the team, especially the operating surgeon and attending cardiology staff, be directly and personally accomplished and recorded in the patient record.

Suggested Readings

1. Bacchetta MD, Wilson K, Girardi LN, et al. Outcomes of cardiac surgery in nonagenarians: a 10-year experience. *Ann Thorac Surg*. 2003;75(4):1215-1220.
2. Benjamin EJ, Blaha MJ, Chiuve SE, et al. Heart disease and stroke statistics-2017 Update: A report from the American Heart Association. *Circulation*. 2017;135(10):e146-e603.
3. Bradley SM, Liu W, Chan PS, et al. Defibrillation time intervals and outcomes of cardiac arrest in hospital: retrospective cohort study from Get With The Guidelines-Resuscitation registry. *BMJ*. 2016;353:i1653.
4. De Laria GA, Tyner JJ, Hayes CL, Armstrong BW. Heparin-protamine mismatch. A controllable factor in bleeding after open heart surgery. *Arch* Surg. 1994;129(9):944-950; discussion 950-951.
5. Despotis G, Avidan M, Eby C. Prediction and management of bleeding in cardiac surgery. *J Thromb Haemost*. 2009;7 Suppl 1:111-117.
6. Frojd V, Jeppsson A. Reexploration for Bleeding and Its Association With Mortality After Cardiac Surgery. *Ann Thorac Surg*. 2016;102(1):109-117.
7. Garmo C, Bajwa T, Burns B. Physiology, Clotting Mechanism, in Stat Pearls. 2018, Stat Pearls Publishing. Treasure Island (FL).
8. Karthik S, Grayson AD, McCarron EE, Pullan DM, Desmond MJ. Reexploration for bleeding after coronary artery bypass surgery: risk factors, outcomes, and the effect of time delay. *Ann Thorac Surg*. 2004;78(2):527-534; discussion 534.

9. Klein AA, Collier T, Yeates J, et al. The ACTA PORT-score for predicting perioperative risk of blood transfusion for adult cardiac surgery. *Br J Anaesth*. 2017;119(3):394-401.

10. La Par DJ, Isbell JM, Mulloy DP, et al. Planned cardiac reexploration in the intensive care unit is a safe procedure. *Ann Thorac Surg*. 2014;98(5):1645-1651; discussion 1651-1652.

11. Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: Adult Advanced Cardiovascular Life Support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132 (18 Suppl 2):S444-464.

12. Lopes CT, Brunori EHFR, Santos VB, et al. Predictive factors for bleeding-related reexploration after cardiac surgery: A prospective cohort study. *Eur J Cardiovasc Nurs*. 2016;15(3):e70-e77.

13. McQuilten ZK, Crighton G, Brunskill S, et al. Optimal Dose, Timing and Ratio of Blood Products in Massive Transfusion: Results from a Systematic Review. *Transfus Med Rev*. 2018;32(1):6-15.

14. Nascimento B, Goodnough LT, Levy JH. Cryoprecipitate therapy. *Br J Anaesth*. 2014;113(6):922-934.

15. Nearman H, Klick JC, Eisenberg P, Pesa N. Perioperative complications of cardiac surgery and postoperative care. *Crit Care Clin*. 2014;30(3):527-555.

16. O'Grady NP, Alexander M, Burns LA, et al. Summary of recommendations: Guidelines for the Prevention of Intravascular Catheter-related Infections. *Clin Infect Dis*. 2011;52(9):1087-1099.

17. Practice Guidelines for blood component therapy: A report by the American Society of Anesthesiologists Task Force on Blood Component Therapy. *Anesthesiology*. 1996;84(3):732-747.

18. Rushing GD, Yuh DD. Primary Coronary Artery Bypass Surgery, in Johns Hopkins Textbook of Cardiothoracic Surgery, Yuh DD, et al, Editors. 2014, McGraw-Hill Education: New York, NY.
19. The Society of Thoracic Surgeons Expert Consensus for the Resuscitation of Patients Who Arrest After Cardiac Surgery. *Ann Thorac Surg*. 2017;103(3):1005-1020.

Suggested Websites

1. https://accesssurgery.mhmedical.com/content.aspx?sectionid=80030289&bookid=1340&jumpsectionID=80030357&Resultclick=2 Accessed: July 19, 2018
2. Copyright ○ 2018 McGraw-Hill Education. All rights reserved. In https://accesssurgery.mhmedical.com/content.aspx?sectionid=80030289&bookid=1340&jumpsectionID=80030357&Resultclick=2 McGraw-Hill Education: McGraw-Hill Education.

Chapter 17

MANAGEMENT OF LIFE-THREATENING ELECTROLYTE AND METABOLIC DISTURBANCES

✓ Objectives

- Review the emergent management of severe electrolyte disturbances.
- Recognize manifestations of acute adrenal insufficiency and initiate appropriate treatment.
- Describe the management of severe hyperglycemic syndromes.

Case Study

A 65-year-old man with altered mental status is brought into the emergency department by his son. His son states the patient has been increasingly weak for the past 3 days. He adds that he has been having multiple episodes of non-bloody diarrhea with decreased appetite. Further history reveals the son has yet to install an air conditioning unit in the patient's room at home even though it is the middle of summer. The patient is unable to provide additional information because of his confusion. His initial vital signs are as follows: blood pressure of 104/66 mm Hg, heart rate of 111 beats/min, respiratory rate of 18 breaths/min, oxygen saturation level of 99% on room air, and temperature of 36.9ºC (98.4°F). Examination findings include an awake Caucasian male not oriented to place, time, or person. He appears clinically dehydrated with dry mucous membranes and poor skin turgor with tenting. The electrocardiogram shows frequent premature ventricular contractions.

– What risk factors does this patient have for electrolyte disturbances?

– Which electrolyte abnormalities might contribute to his presentation?

– How would you initiate the evaluation and treatment of this patient?

I. INTRODUCTION

Electrolyte and metabolic disturbances are common in critically ill and injured patients. These abnormalities alter physiologic function and contribute to morbidity and mortality. The most common life-threatening electrolyte and metabolic disorders in critically ill patients are disturbances in potassium, sodium, calcium, magnesium, phosphate, and glucose levels. With early recognition and treatment of these abnormalities, potentially life-threatening complications may be avoided and outcomes improved.

II. ELECTROLYTE DISTURBANCES

Electrolyte disturbances result from an underlying disease process or iatrogenic causes. It is important to seek the cause of the abnormality, as well as to treat the electrolyte change itself. Many clinical manifestations are not specific to a particular electrolyte change and may be the result of multiple abnormalities. The urgency of treatment depends on the clinical circumstances rather than the absolute electrolyte concentration. All severe electrolyte abnormalities require frequent reassessment during correction.

A. Potassium

Potassium is primarily an intracellular cation that is essential for maintenance of the electrical membrane potential. Its normal range is 3.5–5.0 mEq/L (3.5–5.0 mmol/L). Most potassium (95% to 98%) is found intracellularly and the remainder is present in the extracellular compartment. Potassium plays an important role in maintaining cellular function in excitable tissues. Alterations in this cation primarily affect the cardiovascular, neuromuscular, and gastrointestinal systems.

1. Hypokalemia

Hypokalemia (potassium level < 3.5 mEq/L [< 3.5 mmol/L]) is a common electrolyte disorder. It results from renal or extrarenal losses, transcellular shifts, and decreased intake (**Table 17-1**). Life-threatening clinical manifestations of hypokalemia primarily involve the cardiac and neuromuscular systems. Dysrhythmias (ventricular and supraventricular, conduction delays, sinus bradycardia), electrocardiogram (ECG) abnormalities (U waves, QT-interval prolongation, flat or inverted T waves), muscle weakness or paralysis, paresthesias, ileus, abdominal cramps, nausea, and vomiting are common manifestations.

Table 17-1 Causes of Hypokalemia

Transcellular Shifts	Renal Losses	Extrarenal Losses	Decreased Intake
Acute alkalosis	Diuresis	Diarrhea	Malnutrition
Hyperventilation	Metabolic alkalosis	Profuse sweating	Alcoholism
Insulin	Renal tubular defects	Nasogastric suction	
β-Adrenergic agonists	Diabetic ketoacidosis		
	Drugs (diuretics, aminoglycosides, amphotericin B)		
	Hypomagnesemia		
	Vomiting		
	Hyperaldosteronism		
	Cushing syndrome		

!

Always consider the possibility of hypomagnesemia when significant hypokalemia exists.

!

Treatment of hypokalemia is aimed at correcting the underlying cause and administering potassium (**Figure 17-1**). Discontinuing offending drugs (if possible), correcting hypomagnesemia and other electrolyte disturbances, and correcting alkalosis should be completed as part of the treatment process. Because potassium is primarily an intracellular ion, an estimated deficit cannot be calculated from serum values. Therefore, administration must be titrated against periodic reassessment of the serum levels. Infusion of 20 m Eq (20 mmol) potassium in 100-mL fluid over 1 hour, with additional doses administered sequentially, is recommended to avoid potential complications with more concentrated solutions. This concentration must be administered through a central line, although more dilute solutions can be administered peripherally. The infusion rate can be slowed after life-threatening symptoms resolve. Concentrations and rates may vary by institutional policy. Serum potassium levels must be monitored at frequent intervals during repletion (ie, every 3–4 hours during initial replacement). If acidemia is present, correct the potassium level before correcting the pH because potassium shifts intracellularly as the pH increases.

2. Hyperkalemia

Hyperkalemia (potassium levels > 5 mEq/L [> 5mmol/L]) is very common in the critical care setting and most often results from renal dysfunction or overzealous replacement. Other causes of hyperkalemia are listed in **Table 17-2**. Pseudohyperkalemia may result from a white blood cell count > 100,000/mm^3, a platelet count > 600,000/mm^3, or secondary to phlebotomy technique resulting in hemolysis. Pseudohyperkalemia is a potential cause of hyperkalemia and should be ruled out prior to commencement of treatment, especially if the measured potassium level is not consistent with a previous trend without an obvious disease process to explain the elevation.

Figure 17-1. Treatment of Hypokalemia

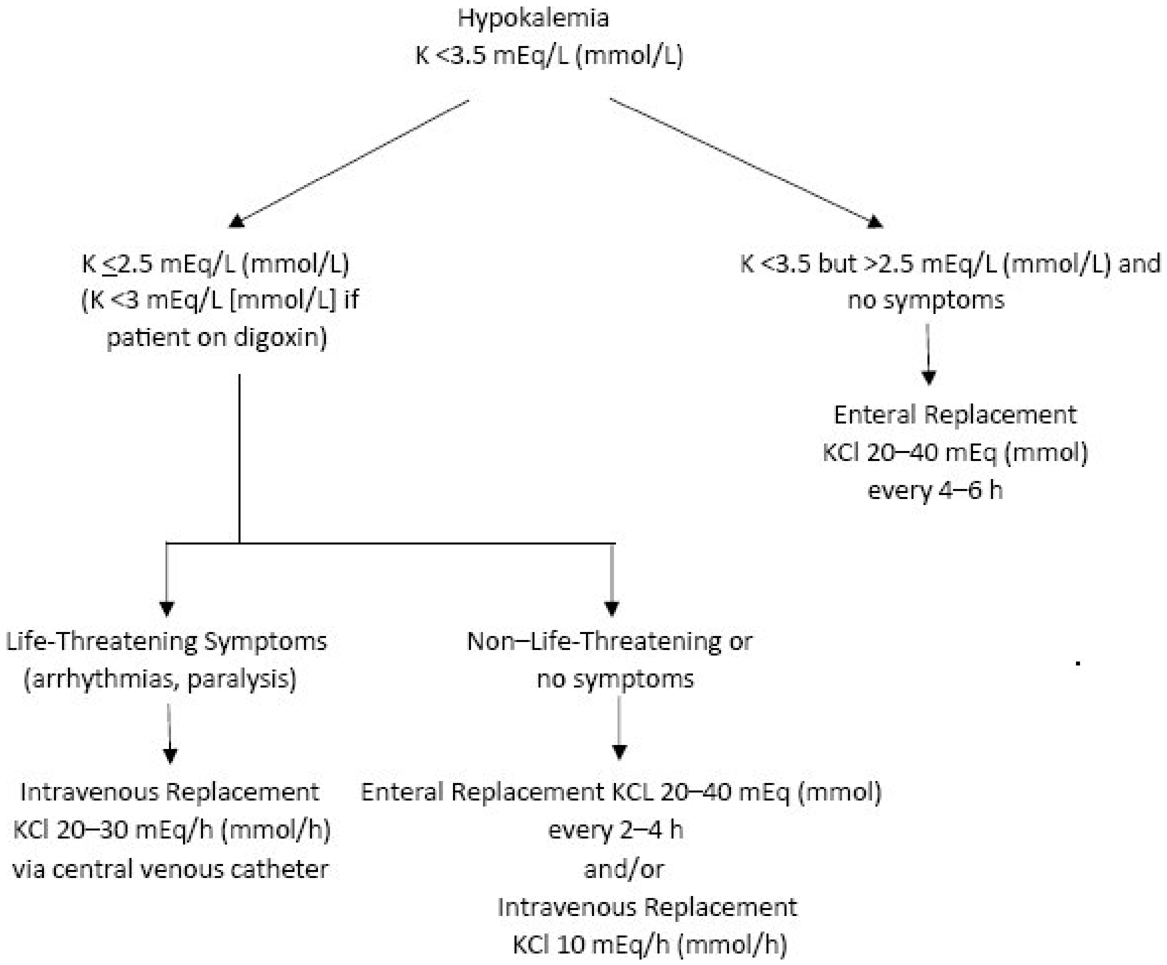

Hypokalemia
K <3.5 mEq/L (mmol/L)
K ≤2.5 mEq/L (mmol/L) (K <3 mEq/L [mmol/L] if patient on digoxin)
K <3.5 but >2.5 mEq/L (mmol/L) and no symptoms
Enteral Replacement KCl 20–40 mEq (mmol) every 4–6 h
Life-Threatening Symptoms (arrhythmias, paralysis)
Non–Life-Threatening or no symptoms
Intravenous Replacement KCl 20–30 mEq/h (mmol/h) via central venous catheter
Enteral Replacement KCL 20–40 mEq (mmol) every 2–4 h and/or Intravenous Replacement KCl 10 mEq/h (mmol/h)

Table 17-2 Causes of Hyperkalemia

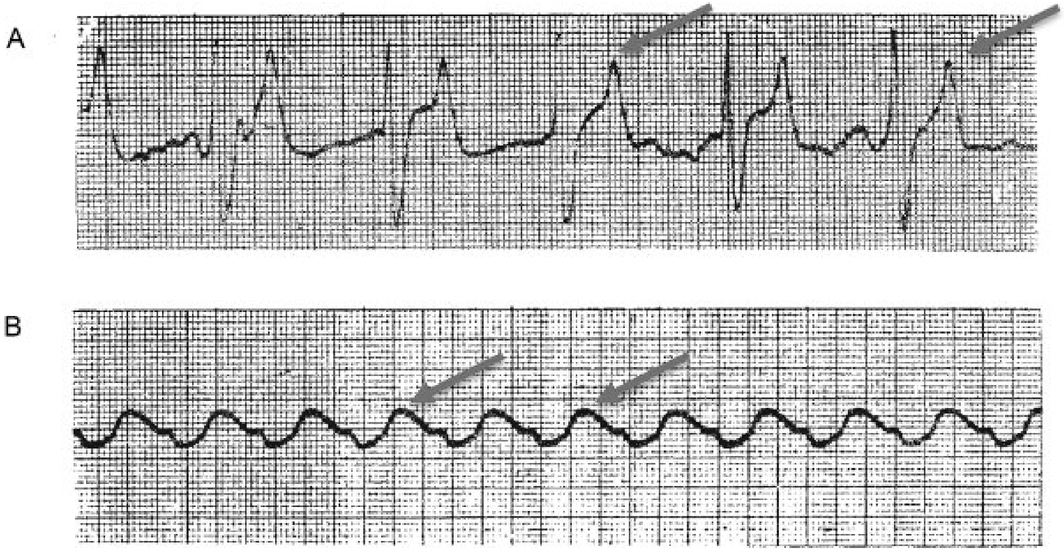
- Renal dysfunction
- Acidemia
- Hypoaldosteronism
- Drugs (eg, potassium-sparing diuretics, angiotensin-converting enzyme inhibitors, succinylcholine, nonsteroidal anti-inflammatory drugs, trimethoprim-sulfamethoxazole)
- Cell death
  - Rhabdomyolysis
  - Tumor lysis
  - Burns
  - Hemolysis
- Excessive intake

> *Hyperkalemia with significant ECG changes, such as widened QRS and sine wave, mandates immediate therapy.*

In the evaluation of a patient with hyperkalemia, a complete medical history and physical examination and an accurate reconciliation of patient medication therapy are vital. Clinical manifestations of hyperkalemia relate primarily to the heart and muscular system (**Figure 17-2**). Arrhythmias, heart block, bradycardia, diminished conduction and contraction, ECG abnormalities (eg, diffuse peaked T waves, PR interval prolongation, QRS widening, diminished P waves, sine waves), muscle weakness, paralysis, paresthesias, and hypoactive reflexes are common manifestations.

Treatment of hyperkalemia involves the recognition and treatment of underlying diseases, the removal of offending drugs, the limitation of potassium intake, and the correction of acidemia or electrolyte abnormalities. Any serum potassium level > 6 mEq/L (6 mmol/L) should be addressed, but the urgency of treatment depends on the clinical manifestations and ECG findings. Options for treating hyperkalemia are summarized in **Table 17-3**. Serial serum potassium levels, continuous cardiac monitoring, and serial ECG tracings should be obtained during evaluation and treatment.

Figure 17-2. Electrocardiographic Effects of Hyperkalemia



Two rhythm strips showing the electrocardiographic effects of hyperkalemia. **A**, peaked T waves and widened QRS complex. **B**, sine wave pattern.

Table 17-3 Options for Treating Hyperkalemia

If Significant Electrocardiographic Abnormalities Are Present

Administer calcium chloride, 5–10 mL of a 10% solution, intravenously over 5–10 minutes to stabilize the myocardial cell membrane and decrease the potential for arrhythmias. If calcium gluconate is used, 10–20 mL of a 10% solution is needed for treatment because of the lower elemental calcium content. The effect lasts only 30–60 minutes and should be followed by additional treatment.

For Redistribution of Potassium

1. Administer insulin and glucose (10 units of regular insulin with 50 g of 50% dextrose over 5–10 minutes intravenously). Glucose monitoring is necessary to avoid hypoglycemia.
2. Administer sodium bicarbonate (1 mEq/kg [1 mmol/kg IV] over 5–10 minutes). Be aware of the potential for sodium overload. Sodium bicarbonate is less effective than glucose and insulin for decreasing the potassium level in patients with end-stage renal failure.
3. Administer inhaled β_2-agonists in high doses (albuterol [salbutamol], 10–20 mg), which can decrease serum potassium by approximately 0.5 mEq/L (0.5 mmol/L).

For Removal of Potassium From the Body

1. Increase urine output with a loop diuretic (furosemide, 1–2 mg/kg) and isotonic fluids.
2. Increase gastrointestinal potassium loss with sodium polystyrene, 25–50 g in sorbitol, enterally or by enema. (Be aware of potential for sodium overload. This may not be a good option in critical illness.) Newer potassium binders (eg, patiromer, sodium zirconium cyclosilicate) have only been studied in the treatment of chronic/non-acute hyperkalemia and have little to no data in the setting of acute hyperkalemia treatment.
3. Initiate dialysis.

B. Sodium

Disorders of sodium and water balance are common in critical illness. Multiorgan failure, fluid therapy, and the numerous therapies administered to patients admitted to the ICU can interfere with the different mechanisms that maintain total body sodium and water homeostasis. Sodium is the principal osmolyte in the extracellular fluid and determines the size of the extracellular volume. Sodium functions as the primary determinant of blood osmolality and is involved in the regulation of extracellular volume. Abnormalities in circulating sodium primarily affect neuronal and neuromuscular function.

When discussing osmolality and tonicity, the osmolality of a solution is determined by the numbers of solutes per kilogram. Plasma (serum) osmolality can be calculated by freezing point depression or using the following formula:

$$2\ (\mathrm{Na})\ [\mathrm{mEq/L}] + \mathrm{Glucose}\ (\mathrm{mg/dL})/18 + \mathrm{BUN}\ (\mathrm{mg/dL})/2.8\ \text{Normal value: } 275\text{–}295\ \mathrm{mOsm/kg}\ H_2O$$

The difference between measured osmolality and calculated osmolality is $<$ 10 mOsm/kg H_2O. Water moves freely between the intracellular and extracellular spaces based on the osmotic gradient with the osmolality of both compartments being virtually identical. It is important to remember that sodium is the major determinant of plasma tonicity. Tonicity is the relative concentration of solutes dissolved in solution which determine the direction and extent of diffusion

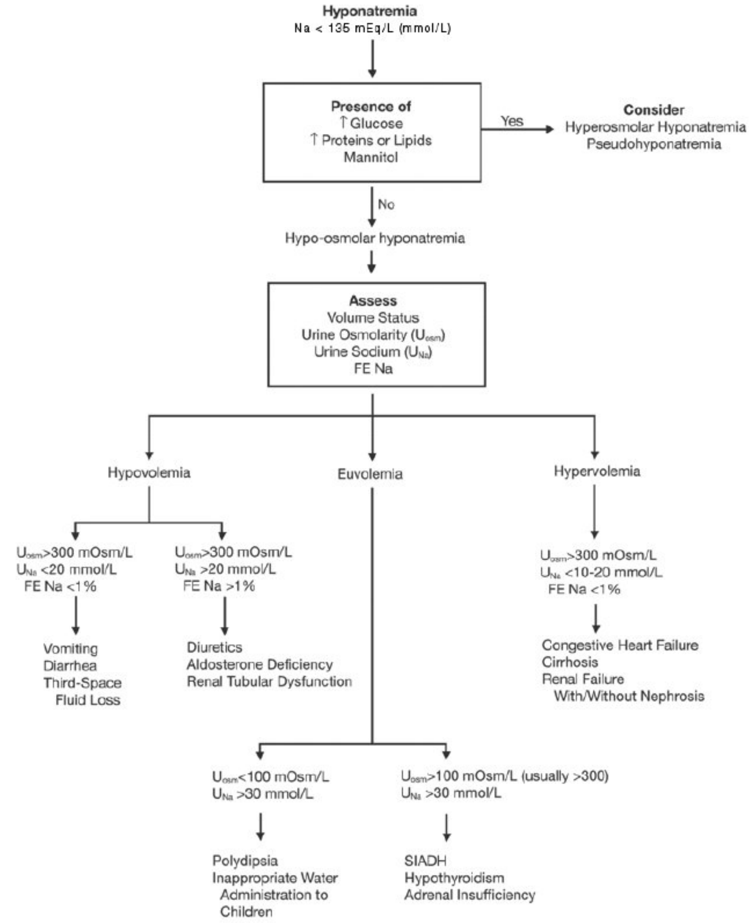
Thirst mechanism and antidiuretic hormone (ADH) tightly control osmolality. ADH stimulates reabsorption of water within the collecting ducts of the kidney. Increases in tonicity produce stimulation of thirst and ADH. Disorder in osmolality reflects impaired water homeostasis and pathologic abnormalities of these mechanisms.

1. Hyponatremia

By definition, hyponatremia is a serum sodium concentration below 135 mEq/L (135 mmol/L). Pseudohyponatremia, a spurious form of iso-osmolar hyponatremia, may occur in the presence of severe hyperlipidemia, hyperproteinemia, or hyperglycemia when the sodium concentration is measured by flame photometry. Serum osmolality determines true hyponatremia. A serum osmolality value of 280–295 mOsm/kg indicates pseudohyponatremia as a result of hyperlipidemia or hyperproteinemia. A serum osmolality value of greater than 295 mOsm/kg indicates hyperglycemia or the use of mannitol as the cause of low serum sodium levels. True hyponatremia is indicated when the serum osmolality value is less than 280 mOsm/kg.

If serum osmolality rules out hyperglycemia or mannitol as the source of hyponatremia and that true hyponatremia is present, the volume status of the patient needs to be evaluated. Clinical presentation, along with urine osmolality and urine sodium, are used to determine volume status. Fractional excretion of sodium is an additional value that can aid in determination of volume status. A urine sodium level of < 100 mOsm/kg indicates a low solute level from primary polydipsia, low sodium intake, or beer potomania. A urine sodium level > 100 mOsm/kg indicates a disturbance in sodium/water balance. Hypovolemia, euvolemia, or hypervolemia is determined using the clinical diagnosis and presentation. Review of the medication administration record needs to be completed to identify any medications that could affect sodium-water balance needs. Urine sodium and fractional excretion of sodium (FENa) values narrow the underlying cause of the hyponatremia to correctly manage the disorder and correct the sodium level.

Figure 17-3. Diagnostic Approach to the Etiology of Hyponatremia


Hyponatremia
Na < 135 mEq/L (mmol/L)
Presence of
↑ Glucose
↑ Proteins or Lipids
Mannitol
Yes
Consider
Hyperosmolar Hyponatremia
Pseudohyponatremia
No
Hypo-osmolar hyponatremia
Assess
Volume Status
Urine Osmolarity (Uosm)
Urine Sodium (UNa)
FE Na
Hypovolemia
Euvolemia
Hypervolemia
Uosm>300 mOsm/L
UNa <20 mmol/L
FE Na <1%
Vomiting
Diarrhea
Third-Space
Fluid Loss
Uosm>300 mOsm/L
UNa >20 mmol/L
FE Na >1%
Diuretics
Aldosterone Deficiency
Renal Tubular Dysfunction
Uosm>300 mOsm/L
UNa <10-20 mmol/L
FE Na <1%
Congestive Heart Failure
Cirrhosis
Renal Failure
With/Without Nephrosis
Uosm<100 mOsm/L
UNa >30 mmol/L
Polydipsia
Inappropriate Water
Administration to
Children
Uosm>100 mOsm/L (usually >300)
UNa >30 mmol/L
SIADH
Hypothyroidism
Adrenal Insufficiency

Abbreviations: FE_{Na}, fractional excretion of sodium; SIADH, syndrome of inappropriate antidiuretic hormone

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Adrenal insufficiency should be ruled out in patients with euvolemic and hypovolemic hyponatremia.

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Clinical manifestations of hyponatremia involve the central nervous system (CNS) and muscular system and include disorientation, decreased mentation, irritability, seizures, lethargy, coma, nausea/vomiting, weakness, and respiratory arrest. Treatment requires identifying the type of hyponatremia, treating the underlying disease, removing offending drugs, and improving the circulating sodium level. Hypovolemic hyponatremia usually responds to intravascular volume repletion (ie, with normal saline). As volume is replaced, the release of ADH is appropriately suppressed and the kidneys begin to excrete free water. Hypervolemic hyponatremia is usually not severe and improves with successful treatment of the underlying condition.

Euvolemic hyponatremia is almost always secondary to elevated levels of ADH. Diagnosis is facilitated by determining urine osmolality before treatment (especially with diuretics) to compare with a calculated serum osmolality. If the hyponatremia is acute or the patient is symptomatic, the serum sodium level should be increased by restricting free-water intake, increasing free-water clearance with loop diuretics, and replacing intravascular volume with normal saline (154 mEq/L [154 mmol/L]) or hypertonic 3% saline (513 mEq/L [513 mmol/L]).

Hypertonic saline is indicated for treatment in the presence of severe symptoms, such as seizures, coma, or impending respiratory arrest. The goal of therapy in this situation is to remove free water and not sodium. The increase in serum sodium should be controlled, and although the precise rate of increase is controversial, the serum sodium increase should be limited to approximately 6 to 8 mmol/L in the first 24 hours. However, one option is to accelerate the rate of serum sodium elevation early in the treatment course in the presence of life-threatening symptoms, such as seizures, and then slow the rate of increase after resolution of the symptoms with a proper strategy to minimize a potential demyelination lesion as a result of a unplanned rapid correction. When hypertonic saline is used in symptomatic patients, 1 mmol/kg sodium chloride should be infused initially (3% saline contains ~0.5 mmol/mL). The same amount can be administered in incremental doses to a maximum of 3 to 5 mmol/kg or until symptoms resolve. Alternatively, the change in serum sodium expected after administering 1 liter of 0.9% normal saline can be estimated by using the following formulas:

$$\text{Change in Serum Sodium} = \frac{\text{Infusate Sodium} - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

$$\text{Change in Serum Sodium} = \frac{(\text{Infusate Sodium} + \text{Infusate Potassium}) - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

$$\text{Total Body Water} = 0.6 \times \text{Weight (kg) for men; } 0.5 \times \text{Weight (kg) for women}$$

The sodium concentrations of various infusates are listed in **Table 17-4**. The formulas presented previously do not take into account other fluid gains (ie, tube feeds or continuous medication infusions) and losses (ie, urine output), and therefore, should serve only as guides to intervention. Serum sodium levels should be monitored at frequent intervals during therapy for hyponatremia, at least every 6 hours. When serum sodium is greater than 125 to 130 mEq/L (125 to 130 mmol/L), restriction of free water alone allows for slower return of the sodium level to normal.

!

Do not use vasopressin antagonists in patients with severe neurologic symptoms and do not co-administer with hypertonic saline.

!

Correction of the serum sodium level that is too rapid may result in CNS injury (ie, osmotic demyelinating syndrome), particularly in the setting of chronic hyponatremia. Osmotic demyelinating syndrome rarely occurs in patients whose serum sodium is greater than 120 mEq/L (120 mmol/L). Symptoms of demyelination are typically seen after initial improvement in mentation. In 1 to 7 days following a hasty reversal of chronic hyponatremia, patients may develop focal motor deficits, respiratory insufficiency, and progressive loss of consciousness. Patients at greatest risk for osmotic demyelinating syndromes are those with malnutrition, hypokalemia, alcohol abusers, elderly women, and burn patients. If hyponatremia is chronic and the patient is asymptomatic, regardless of the magnitude of hyponatremia, free-water restriction alone may be sufficient to allow for slow return of serum sodium to normal.

Table 17-4 Sodium Characteristics of Selected Infusates

Infusate	Sodium Concentration (mmol/L)
5% sodium chloride	855
3% sodium chloride	513
0.9% sodium chloride	154
Ringer lactate solution	130
0.45% sodium chloride	77
5% dextrose in water	0

Although controversial, vasopressin receptor antagonists, such as conivaptan and tolvaptan, are available for use in the management of hyponatremia. These agents should not be used in the management of acute hyponatremia and expert consultation should be sought before their use. They inhibit resorption of water via their action on the V2 receptor of the kidney and result in a slow rise in the serum sodium level. Vasopressin receptor antagonists can cause hypotension and volume depletion and therefore should be avoided in patients with hypovolemia. After a vasopressin receptor antagonist is administered, serum sodium levels should be monitored frequently (every 4 hours) because of concerns for rapid sodium correction and neurologic sequelae (specifically, demyelination). To prevent over-correction, avoid using vasopressin antagonists in combination with hypertonic saline. Once an increase of 6 to 8 mmol/L is achieved, consider replacing free water (orally or intravenously) to match urine output and prevent an excessive rise in sodium levels.

2. Hypernatremia

Hypernatremia (sodium > 145 mEq/L [145 mmol/L]) indicates intracellular volume depletion with a loss of free water that exceeds sodium loss. Causes of hypernatremia are listed in **Table 17-5**.

Table 17-5 Causes of Hypernatremia

Water Loss	Reduced Water Intake	Excessive Sodium Intake
Diarrhea	Altered thirst	Salt tablets
Vomiting	Impaired access	Hypertonic saline
Excessive sweating		Sodium bicarbonate
Diuresis		
Diabetes insipidus		

The clinical manifestations of hypernatremia relate to CNS and muscle function. Manifestations of hypernatremia include altered mentation, lethargy, seizures, coma, and muscle weakness. Polyuria suggests the presence of diabetes insipidus or excess salt and water intake.

Treatment focuses on correcting the underlying cause of hypernatremia. Nearly all patients with hypernatremia require free-water repletion. The water deficit can be estimated by using the following equation:

Water Deficit (L) = 0.6 (0.5 for women) × weight (kg) [(measured Na/normal Na) – 1]

Example: Water deficit of a 70-kg man with sodium measurement of 160 mEq/L (mmol/L)
$0.6 \times 70\ [(160/140) - 1]$
$42\ [1.14 - 1]$
$42 \times 0.14 = 5.88$ L water deficit

A portion of the free-water deficit should be replaced initially at a speed commensurate with the severity of symptoms, and the patient should be reevaluated for subsequent replacement frequently (monitor sodium levels every 6 hours). Regardless of the serum sodium level, if the patient shows signs of hypovolemic shock (eg, hypotensive, orthostatic, or significantly tachycardia), administer normal saline until the intravascular volume is corrected. When the patient is hemodynamically stable, replete the remaining water deficit with 5% dextrose in water, 0.45% NaCl, or 0.2% NaCl with 5% dextrose. To estimate the change in serum sodium expected after administering 1 liter of fluid, use the same formulas as for hyponatremia:

$$\text{Change in Serum Sodium} = \frac{\text{Infusate Sodium} - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

$$\text{Change in Serum Sodium} = \frac{(\text{Infusate Sodium} + \text{Infusate Potassium}) - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

In stable patients, water may be replaced via the enteral route (ie, nasogastric tube). In the rare patient with extreme sodium overload, sodium may be removed with loop diuretics or dialysis (provided intravascular volume is adequate). Administration of aqueous vasopressin or desmopressin should be considered for patients with central diabetes insipidus.

> ❗
>
> *Rapid correction of serum sodium can result in cerebral edema and neurologic injury.*
>
> ❗

Sodium concentrations should be measured frequently during treatment, and therapy should be adjusted for optimal correction of the sodium level. If hypernatremia developed over a period of hours, reducing the serum sodium by 1 mEq/L/h (1 mmol/L/h) is appropriate. In hypernatremia of longer or unknown duration, a slower rate of correction (0.5 mEq/L/h [0.5 mmol/L/h]) is recommended. Increasing free-water intake in maintenance fluids allows for a slow return to normal sodium levels.

C. Other Electrolyte Abnormalities

1. Calcium

Calcium is the most abundant mineral in the body, comprised of 50% active ionized calcium and 50% calcium bound to albumin in extracellular fluid. It is required for muscle contraction, nerve impulse transmission, hormone secretion, blood clotting, cell division, cell motility, and wound healing. Effective calcium levels in a seriously ill patient are best assessed by using ionized calcium measurements, if available. Total serum calcium is directly related to serum albumin whereas ionized calcium is inversely related to serum albumin. In general, for each increase or decrease in serum albumin of

1 g/dL, the serum calcium increases or decreases by 0.8 mg/dL (0.2 mmol/L). However, the relationship between albumin and serum calcium is less reliable in critically ill patients.

a. Hypocalcemia

Hypocalcemia (total calcium < 8.5 mg/dL [< 2.12 mmol/L], ionized calcium < 4 mg/dL [1 mmol/L]) is common in critically ill patients and results from impairment of the parathyroid and/or vitamin D systems (**Table 17-6**). Cardiovascular abnormalities, the most common clinical manifestations of hypocalcemia in critically ill patients, include hypotension, bradycardia, arrhythmias, heart failure, cardiac arrest, digitalis insensitivity, and QT interval and ST-segment prolongation. Neuromuscular manifestations include weakness, muscle spasm, laryngospasm, hyperreflexia, seizures, tetany, and paresthesias.

Table 17-6 Causes of Hypocalcemia

- Hypoparathyroidism
- Sepsis
- Burns
- Rhabdomyolysis
- Pancreatitis
- Malabsorption
- Liver disease
- Renal disease
- Calcium chelators
- Hypomagnesemia
- Massive transfusion

Treatment is aimed at correcting the underlying disease process and any concomitant electrolyte abnormalities, and administering calcium. Mild hypocalcemia is well tolerated, and aggressive treatment may result in tissue injury (especially during ischemic and septic states). If the hypocalcemia is severe (ionized calcium < 4 mg/dL [1 mmol/L]) or if the patient is symptomatic, administer 100 mg calcium intravenously over 5 to 10 minutes (3–4 mL of 10% calcium chloride or 10 mL of 10% calcium gluconate), followed by calcium in the amount of 0.3 to 2 mg/kg/h. Calcium preparations vary in their content of elemental calcium: 1 g of 10% calcium chloride contained in 10 mL has 272 mg of calcium; 1 g of 10% calcium gluconate contained in 10 mL has 90 mg of calcium. When the circulating calcium concentration is stable, calcium may be replaced via the enteral route (ie, 500–1,000 mg every 6 hours).

Monitor ionized or total calcium levels frequently during treatment, and adjust repletion to maintain calcium in the lower normal range so as not to suppress parathyroid gland function. If calcium replacement alone fails to maintain the circulating calcium level, consider administration of vitamin D and confirm normal magnesium levels. Adverse effects of calcium administration include hypercalcemia, bradycardia, nausea/vomiting, flushing, and tissue calcium precipitation.

b. Hypercalcemia

The most common causes of hypercalcemia (total calcium > 11 mg/dL [> 2.75 mmol/L], ionized calcium > 5.21 mg/dL [1.3 mmol/L]) are the result of calcium release from bone (**Table 17-7**). The clinical manifestations of hypercalcemia relate primarily to the cardiovascular and neuromuscular systems and include hypertension, cardiac ischemia, arrhythmias, bradycardia, conduction abnormalities, digitalis toxicity, dehydration, hypotension, weakness, depressed mentation, coma, seizures, and sudden death. Gastrointestinal manifestations include nausea/vomiting, anorexia, abdominal pain, constipation, pancreatitis, and ulcer disease. Nephrogenic diabetes insipidus with polyuria may occur and contribute to volume depletion. Renal stones, nephrocalcinosis, and renal failure may also be encountered.

Table 17-7 Causes of Hypercalcemia

Hyperparathyroidism
Malignancy
Immobilization
Excess intake of vitamin A or vitamin D
Thyrotoxicosis
Granulomatous disease

> Treatment of hypercalcemia is aimed at controlling the underlying disease, rehydrating the patient, and lowering the calcium level. The circulating calcium level frequently needs to be lowered while the primary disease is being evaluated and treated. Intravascular volume should be restored with normal saline to ensure adequate tissue perfusion and renal blood flow (urine output 2–3 mL/kg/h). Saline also decreases renal tubular calcium reabsorption. Once adequate volume status is secured, diuresis with a loop diuretic further increases calcium excretion. Serum potassium and magnesium levels should be monitored and low levels corrected. In patients with renal failure, pulmonary edema, or life-threatening hypercalcemia, calcium levels may be lowered with dialysis. After initial stabilization, therapy with calcitonin and bisphosphonates can be considered.

2. Phosphorus

Phosphate is important in cellular energy metabolism. Hypophosphatemia (phosphate < 2.5 mg/dL [0.81 mmol/L]) results from transcellular shifts, renal loss, gastrointestinal loss, or inadequate intake (**Table 17-8**). Phosphate depletion primarily affects the neuromuscular and central nervous systems. Clinical manifestations include muscle weakness, respiratory failure, rhabdomyolysis, paresthesias, lethargy, disorientation, obtundation, coma, and seizures. Other possible complications include impaired renal tubular function, impaired pressor response, hepatic dysfunction, immune dysfunction, impaired protein synthesis, hemolysis, impaired platelet function, and impaired oxygen off-loading from hemoglobin.

Treatment of hypophosphatemia consists of controlling the underlying disease, removing offending drugs, correcting electrolyte abnormalities, and replacing phosphate. Phosphate levels < 1 mg/dL (< 0.32 mmol/L) associated with symptoms are considered life-threatening and require immediate treatment. For emergency treatment, administer phosphate at 0.6 to 0.9 mg/kg daily intravenously. When circulating levels are stable, maintenance replacement of phosphate is 1,000 mg/day intravenously plus excess estimated losses (ie, in urine or stool). Phosphate may be administered as potassium phosphate (93 mg/mL phosphate, 1.1 mmol/mL potassium) or sodium phosphate (93 mg/mL). Enteral administration of phosphate is preferred in patients with serum phosphate levels > 1.0 to 1.5 mg/dL (> 0.32–0.48 mmol/L).

Table 17-8 Causes of Hypophosphatemia

Transcellular Shift	Renal Loss	Gastrointestinal Loss	Decreased Intake
Acute alkalosis	Hyperparathyroidism	Malabsorption	Malnutrition
Carbohydrate administration	Diuretic use	Diarrhea	Parenteral nutrition
Drugs (insulin, epinephrine)	Hypokalemia	Intestinal fistulas	
	Hypomagnesemia	Antacids	
	Steroids		

Serum phosphate should be monitored during repletion and therapy adjusted to achieve a circulating level of 3 to 4 mg/dL (0.97–1.29 mmol/L). Adverse effects of phosphate administration include hyperphosphatemia, hypocalcemia, tissue calcium precipitation, renal injury, and diarrhea (enteral phosphate).

Hyperphosphatemia is uncommon in critical illness except with renal failure. Increased bone metabolism secondary to tumors or increased gut absorption also may cause hyperphosphatemia. Symptoms are similar to those of hypocalcemia: ventricular arrhythmias, prolonged QT interval, seizures, paresthesias, and muscle cramps. Hyperphosphatemia is treated with intravenous calcium and enteral phosphorus binders. Dialysis may be required with renal failure.

3. Magnesium

Magnesium is important to the body for energy transfer and electrical stability. Causes of hypomagnesemia (magnesium < 1.8 mg/dL [< 0.75 mmol/L]) are listed in **Table 17-9**.

Table 17-9 Causes of Hypomagnesemia

Renal Loss	Gastrointestinal Loss	Transcellular Shift	Decreased Intake
Renal tubular dysfunction Diuresis Hypokalemia Drugs (eg, aminoglycosides, amphotericin)	Malabsorption Diarrhea Nasogastric suction	Refeeding Recovery from hypothermia	Malnutrition Alcoholism Parenteral nutrition

Clinical manifestations of hypomagnesemia overlap those of hypokalemia and hypocalcemia, including cardiovascular abnormalities (ie, QT-interval prolongation, arrhythmias, vasospasm, myocardial ischemia), neuromuscular abnormalities (eg, weakness, tremor, seizures, tetany, obtundation, coma), and electrolyte abnormalities (eg, hypokalemia, hypocalcemia).

Treatment of hypomagnesemia consists of addressing the underlying disease, discontinuing problematic drugs, correcting concomitant electrolyte abnormalities, and replenishing magnesium. For emergency treatment (ie, arrhythmias), administer 1 to 2 g magnesium sulfate intravenously over 5 to 10 minutes. The agent can be administered over a longer interval (10–60 minutes) in less urgent situations. Depending on the clinical situation, subsequent intravenous replacement ranges from 1 to 2 g magnesium sulfate every 4 to 6 hours. Once serum levels stabilize, intravenous maintenance doses are 0.1 to 0.2 mmol/kg daily (1 g magnesium sulfate = 8 mmol). Maintenance magnesium may be administered enterally. The dose should be reduced if renal failure is present. Magnesium levels should be monitored during repletion. Deep tendon reflexes can be used to assess for hypermagnesemia during replacement (ie, decreased at serum level 4–5 mg/dL [1.65–2.06 mmol/L]).

Hypermagnesemia is uncommon in critical illness but may be seen with renal failure or shifts in magnesium from intracellular fluid as a result of soft-tissue injury as with crush injuries, burn trauma, and rhabdomyolysis. Hyporeflexia, lethargy, and apnea may result. Treatment consists of administration of intravenous calcium, diuretic administration, and dialysis in severe cases.

III. METABOLIC DISTURBANCES

Case Study

A 54-year-old woman is admitted to the general medicine floor (day 3) with cellulitis of her left lower extremity. Her medical history is significant for diabetes mellitus (Type 2) and rheumatoid arthritis, and her home medications include metformin, methotrexate, and prednisone. During this admission, she has been started on antimicrobial therapy and insulin glargine. Her home methotrexate and prednisone are on hold to help with healing of her infection. The emergency response team is called because of a new finding of altered mental status, respiratory rate of 22 breaths/min, heart rate of 140 beats/min, blood pressure of 84/42 mm Hg, and temperature of 37.2°C (98.9°F). A complete blood count and basic metabolic panel are unremarkable. She is given a 2-L fluid bolus of lactated Ringer and started on 10 μg/min of norepinephrine and remains hypotensive.

- What metabolic disorder may contribute to this patient's new onset hypotension?
- What interventions should be considered?
- What laboratory tests could confirm this diagnosis?

A. Acute Adrenal Insufficiency

Acute adrenal insufficiency in the critically ill patient, also known as critical illness-related corticosteroid insufficiency (CIRCI), may result from preexisting or previously undiagnosed chronic disease of the adrenal glands or hypothalamic-pituitary axis, or acute conditions affecting these endocrine organs (**Table 17-10**). Patients with chronic disease may develop acute adrenal insufficiency precipitated by infection or other stressors. In addition, functional impairment during serious illness may result from relative or absolute insufficiency of glucocorticoid production, which usually reverses with recovery from the illness. Relative adrenal insufficiency occurs when cortisol response is normal or high, but is reduced relative to the severity of illness.

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Electrolyte abnormalities are less likely with acute adrenal insufficiency compared with chronic adrenal insufficiency.

!

Lack of specific signs and symptoms of acute adrenal insufficiency makes for a challenging early diagnosis in the critically ill population. Clinical manifestations consistent with acute adrenal insufficiency include weakness, nausea and vomiting, abdominal pain, tachycardia, and orthostatic hypotension. A diagnostic clue is hypotension refractory to volume resuscitation. Suggestive laboratory findings may include eosinophilia, hyponatremia, hyperkalemia, acidosis, and hypoglycemia. Acute adrenal hemorrhage may cause abdominal, flank, or back pain. Clinical and laboratory manifestations overlap significantly with manifestations of other common critical illnesses, such as sepsis.

Table 17-10 Etiologies of Adrenal Insufficiency

Chronic Conditions

- Adrenal glands
    - Autoimmune destruction
    - Granulomatous disease (tuberculosis)
    - HIV infection
    - Other infection (cytomegalovirus, fungal)
    - Primary or metastatic malignancy
    - Drug effects (ie, ketoconazole)

- Hypothalamic/pituitary axis
    - Withdrawal from exogenous glucocorticoid therapy
    - Hypopituitarism (tumors, infarction, radiation)
    - Sarcoidosis, histiocytosis
    - Head trauma

Acute Conditions

- Critical illness (affects adrenal glands and hypothalamic-pituitary axis)
    - Hypoperfusion
    - Cytokine effects (altered cortisol metabolism, receptor affinity)

- Acute adrenal hemorrhage
    - Meningococcemia
    - Disseminated intravascular coagulation
    - Anticoagulation (eg, warfarin, heparin)

- Drug effects
    - Increased cortisol metabolism (phenytoin, phenobarbital, rifampin)
    - Interference with glucocorticoid synthesis (ketoconazole, etomidate)

Important clues for possible adrenal insufficiency in critically ill patients are vasopressor-dependent states, failure to respond to appropriate fluid administration, fever without an apparent source, and a discrepancy between the expected disease severity and the patient's condition.

Hydrocortisone also provides some mineralocorticoid effects.

The value of a single test for hypothalamic-pituitary-adrenal axis function is limited. Either a random cortisol level of < 10 μg/dL or a stimulation test may be used to diagnose CIRCI. With the cosyntropin stimulation test, clinicians may use the change in cortisol of less than 9 μg/dL 60 minutes after a 250-μg cosyntropin dose as suggestive of a diagnosis of adrenal insufficiency. Current recommendations call for administration of less than 400 mg of hydrocortisone per day for 3 or more days. Improvement in hemodynamic status after administration of hydrocortisone was previously an important physiologic indicator, but laboratory testing is now preferred. Although corticosteroid therapy is frequently weaned by reducing the dose over a period of 3–5 days, no specific recommendations for weaning exist and many trials did not wean therapy.

B. Hyperglycemic Syndromes

1. Diabetic Emergencies

> *HHS develops over days to weeks and results in greater dehydration than does DKA, which usually evolves in < 24 hours.*

Serious metabolic complications of diabetes mellitus result from a relative or absolute lack of insulin coupled with increased production of counter-regulatory hormones such as glucagon, catecholamines, cortisol, epinephrine, and others. Life-threatening hyperglycemic syndromes include diabetic ketoacidosis (DKA) and hyperglycemic hyperosmolar state (HHS). These syndromes differ in the severity of dehydration and degree of acidosis (ketosis) but share many clinical manifestations and therapeutic interventions. In addition, patients may manifest components of both syndromes. **Table 17-11** lists characteristics that may distinguish the syndromes, but considerable variability is possible. Although DKA and HHS may be the initial presentation of diabetes mellitus, the most common precipitating factors are infection and medication noncompliance. Other precipitants include corticosteroid use, myocardial infarction, stroke, alcohol abuse, pancreatitis, trauma, and pregnancy.

Table 17-11 Characteristics of Hyperglycemic Syndromes

	Diabetic Ketoacidosis	**Hyperglycemic Hyperosmolar State**
Glucose	> 250 mg/dL	> 600 mg/dL
Arterial/venous pH	< 7.3	> 7.3
Anion gap	Increased	Variable
Serum/urine ketones	Positive	Negative or small
Serum osmolality	Normal	Increased

!

The corrected serum sodium concentration [measured sodium + 0.016 × (serum glucose-100)] should be used to assess the severity of dehydration.

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Clinical manifestations result from hyperglycemia in both syndromes and from excess ketone production in DKA. Hyperglycemia causes hyperosmolality, osmotic diuresis, fluid and electrolyte loss, dehydration, and volume depletion. Ketones, specifically beta-hydroxybutyrate and acetate, are responsible for the metabolic acidosis and can be measured indirectly by the anion gap. Clinical features of both hyperglycemic syndromes may include weakness, dehydration, polyuria, polydipsia, tachycardia, hypotension, anorexia, nausea/vomiting, and ileus. Abdominal pain, hyperpnea (Kussmaul respirations), and fruity odor to the breath are more characteristic of DKA, whereas altered mental status (ranging from lethargy to coma) and dysrhythmias are more common in HHS. Laboratory investigation may reveal hyperglycemia, hyperosmolality (more common in HHS), glucosuria, anion gap metabolic acidosis (DKA), hyperkalemia (when acidemia is present) or hypokalemia and hypophosphatemia (after insulin therapy is initiated), lactic acidosis, leukocytosis, and azotemia. Serum sodium concentrations may be low as a result of translocation of water to the extracellular space. An elevated serum sodium concentration suggests severe dehydration.

An initial rapid evaluation of the patient with a possible hyperglycemic condition should include assessment of mental status, degree of dehydration (vital signs, orthostatic changes, urine output), and presence of infection. Laboratory studies should include complete blood count, electrolytes, renal function, glucose (plasma or fingerstick), urine or serum ketones, and arterial blood gas (venous pH can be used as a substitute). An electrocardiogram should be obtained to evaluate for ischemia and changes caused by electrolyte abnormalities. If infection is suspected, appropriate cultures are indicated.

The goals for treatment of hyperglycemic syndromes are to restore the fluid and electrolyte balance, provide insulin, and identify precipitating factors. The initial management of DKA and HHS is outlined in **Table 17-12**. Volume deficits correlate with the severity of hyperglycemia and are usually greater in HHS. Urine output should be maintained at 1 to 3 mL/kg/h to ensure adequate tissue perfusion and clearance of glucose.

The intravenous route for insulin administration is the most reliable and easiest to titrate. Because of the short half-life of intravenous insulin, a continuous infusion is necessary with serial monitoring of the glucose and electrolyte concentrations. Smaller doses of insulin may be adequate in HHS. In the case of DKA, insulin infusion should be continued until the removal of beta-hydroxybutyrate and acetone, as measured by normalization of the anion gap or normalization of beta-hydroxybutyrate levels. Normalization of the anion gap usually occurs many hours after normalization of the serum glucose levels.

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Glucose concentrations should be monitored every 1–2 hours.

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Glucose-containing fluids may be started earlier than recommended if blood glucose cannot be monitored frequently. When glucose and/or serum osmolality are controlled, acidosis has cleared, and the patient is stable, subcutaneous insulin may be administered; an insulin sliding scale of regular and longer-acting preparations can be started and should overlap for 1 to 2 hours with discontinuation of the insulin infusion.

!

Be aware that bicarbonate therapy in addition to insulin will lower the serum potassium concentration.

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Insulin and correction of acidosis shifts potassium intracellularly and may lead to precipitous drops in serum potassium levels. Oral potassium replacement can be considered if nausea and vomiting are not present. Potassium and other electrolyte levels should be monitored frequently (especially in the first 6 hours) until levels stabilize and acidosis is resolved.

Table 17-12 Initial Management of Hyperglycemic Syndromes

Fluids

1. Assess severity of dehydration
2. Institute crystalloid resuscitation, initially with normal saline at approximately 15–20 mL/kg/h in the first hour in the absence of cardiac dysfunction to restore hemodynamic stability and renal perfusion. Subsequent fluid infusion rates should be guided by assessment of hydration and urine output, and 250–500 mL/h is often adequate.
3. After stabilization of the hemodynamic status, fluids with less chloride (eg, 0.45% saline) should be considered to avoid or minimize the development of hyperchloremic metabolic acidosis. The corrected serum sodium should also be used to guide fluid selection.
4. Add glucose to fluids when glucose is 250–300 mg/dL (13.9–16.7 mmol/L) in DKA. Administer 10% dextrose if necessary to maintain glucose >150 mg/dL (>8.3 mmol/L). In HHS, add glucose to fluids when glucose is 300 mg/dL (16.7 mmol/L) to maintain the glucose concentration between 250–300 mg/dL (13.9–16.7 mmol/L).

Insulin

1. Administer a regular insulin loading dose as an intravenous bolus (0.1–0.15 units/kg), followed by an infusion at 0.1 units/kg/h. If potassium concentration is <3.3 mmol/L, hold insulin until potassium is replaced.
2. If the glucose concentration does not fall by 50 mg/dL (2.8 mmol/L) in the first hour, consider increasing the insulin infusion rate or administering additional insulin boluses (10 units regular insulin hourly).
3. In DKA, continue insulin infusion or decrease by 50% when the glucose reaches 300 mg/dL (16.7 mmol/L). Maintain the glucose concentration between 150 and 200 mg/dL (8.3 and 11.1 mmol/L) until acidosis and ketosis are resolved.
4. In HHS, decrease insulin infusion when the glucose concentration reaches 300 mg/dL (16.7 mmol/L) to maintain the glucose at 250–300 mg/dL (13.9-16.7 mmol/L) until the plasma osmolality is ≤315 mOsm/kg and the patient is alert.

Electrolytes

1. If serum potassium is <3.3 mEq/L (mmol/L), hold insulin and administer potassium, 40 mEq/h (mmol/h) as potassium chloride or potassium phosphate (or combination), until potassium is >3.3 mEq/L (mmol/L) to avoid arrhythmias or severe weakness.
2. If serum potassium is >3.3 mEq/L (mmol/L) but <5 mEq/L (mmol/L) and urine output is adequate, administer potassium, 20–30 mEq (mmol), in each liter of fluids to maintain the potassium at 4–5 m Eq/L (mmol/L).
3. If serum potassium is >5 mEq/L (mmol/L), do not administer potassium in fluids until <5 mEq/L (mmol/L).
4. Consider phosphate replacement with potassium phosphate if serum are low (<1 mg/dL, 0.32 mmol/L) or severe symptoms are present.

Abbreviations: DKA, diabetic ketoacidosis; HHS, hyperglycemic hyperosmolar state

Acidosis is well tolerated by patients with DKA, and bicarbonate therapy is controversial. No benefit has been found when bicarbonate is administered to DKA patients with a pH of 6.9 to 7.1, and fluid and insulin therapy results in rapid improvement in pH. Bicarbonate administration may be considered if the arterial pH is < 6.9 (give 100 mmol bicarbonate over 1 hour to increase pH > 7). Do not attempt to normalize blood pH with bicarbonate because acidosis resolves as ketones are metabolized.

2. Hyperglycemia in Critical Illness

Hyperglycemia is common in diabetic and nondiabetic patients with critical illness and may be the result of stress hormones, inflammatory mediators, glucocorticoid therapy, excessive nutritional calories, decreased activity, and other mechanisms. Significant hyperglycemia is associated with poor wound healing, impaired immune function, increased inflammation, endothelial dysfunction, and other adverse effects leading to increased illness and death. Early studies of tight glucose control (80–110 mg/dL, 4.4–6.1 mmol/L) suggested benefit in a surgical population, but this target has been difficult to achieve in subsequent studies without increasing the risk for severe hypoglycemia. In addition, in multiple subsequent trials, no consistent reduction in mortality was observed with intensive control of glucose levels. Some recent studies of tight glycemic control have actually demonstrated increased mortality associated with higher rates of hypoglycemia.

In critically ill patients, insulin therapy should be initiated for persistent hyperglycemia (blood glucose level $>$ 150 mg/dL). Once it has been initiated, a glucose level of 140–180 mg/dL (7.8–10 mmol/L) with the avoidance of hypoglycemia is recommended. Intravenous insulin infusions are the preferred method to achieve and maintain control. During intravenous insulin therapy, frequent monitoring of blood glucose is essential to minimize the risk of hypoglycemia (blood glucose $<$ 70 mg/dL), and achieve optimal control.

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Patients with renal dysfunction require lower rates of insulin infusions.

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The ability to provide adequate nursing support and monitoring may affect the blood glucose goals chosen. Different types of blood sampling and glucose measurement methods may also yield different results. The institution’s protocol for blood sampling, insulin infusion, and glucose management targets should be followed to achieve consistency and minimize the risk of hypoglycemia.

Key Points

Management of Life-Threatening Electrolyte and Metabolic Disturbances

- In the presence of life-threatening dysrhythmias or paralysis associated with hypokalemia, administer potassium chloride, 20 mmol/h, through a central venous catheter.
- If hyperkalemia-associated ECG abnormalities are present, administer calcium chloride or calcium gluconate intravenously over 5 to 10 minutes, then consider shifting potassium intracellularly with 50% dextrose and regular insulin intravenously, inhaled β-agonists, and/or sodium bicarbonate.
- In symptomatic euvolemic hyponatremia, limit the increase in serum sodium to 6 to 8 mmol/L in the first 24 hours. Correction of serum sodium that is too rapid may result in CNS injury.
- Patients with hypernatremia and hemodynamic instability should have normal saline administered until intravascular volume is corrected. Subsequently, replace water deficit with 5% dextrose in water, 0.45% NaCl, or 0.2% NaCl with 5% dextrose. Enteral replacement with water is an effective strategy in stable patients.
- Emergent treatment with a glucocorticoid is indicated in patients with critical illness-related corticosteroid insufficiency (CIRCI) diagnosed by random plasma cortisol or the results of the cosyntropin stimulation test.
- A glycemic target of 140–180 mg/dL is appropriate for most hospitalized patients to provide clinical benefits with a reduced risk of hypoglycemia.
- The goals of treatment in hyperglycemic syndromes are to restore the fluid and electrolyte balance, provide insulin, and identify precipitating factors.
- In diabetic ketoacidosis, insulin infusion should be continued until the ketosis and acidosis have resolved. Glucose-containing fluids

should be administered to prevent hypoglycemia during insulin infusion.

- Maintain the glucose between 250 and 300 mg/dL (13.9–16.7 mmol/L) in hyperglycemic hyperosmolar syndrome until the plasma osmolality is < 315 mOsm/kg and the patient is alert.
- Potassium should be added to the fluid therapy for hyperglycemic syndromes as soon as serum potassium is recognized to be < 5 mmol/L and urine output is adequate.
- A protocol of blood sampling, insulin infusion, and target glucose levels should be followed to avoid hyperglycemia and minimize hypoglycemia in critically ill patients.

Suggested Readings

1. American Diabetes Association. Diabetes care in the hospital: standards of medical care in diabetes – 2020. *Diabetes Care*. 2020;43(Suppl 1):S193-S202.
2. Annane D, Pastores S, Rochwerg B, et al. Guidelines for the diagnosis and management of critical illness related corticosteroid insufficiency (CIRCI) in critically ill patients (Part I): Society of Critical Care Medicine and European Society of Intensive Care Medicine 2017. *Crit Care Med*. 2017;45:2078-2088
3. Annane D, Pastores S, Rochwerg B, et al. Guidelines for the diagnosis and management of critical illness related corticosteroid insufficiency (CIRCI) in critically ill patients (Part II): Society of Critical Care Medicine and European Society of Intensive Care Medicine 2017. *Crit Care Med*. 2018;46:146-148.
4. Berl T. Vasopressin antagonists. *N Engl J Med*. 2015;372:2207-2216.

5. Brown GR, Greenwood JK. Drug- and nutrition-induced hypophosphatemia: mechanisms and relevance in the critically ill. *Ann Pharmacother*. 1994;28:626-632.
6. Charron T, Bernard F, Skrobik Y, et al. Intravenous phosphate in the intensive care unit: more aggressive repletion regimens for moderate and severe hypophosphatemia. *Intensive Care Med*. 2003;29:1273-1278.
7. Gennari FJ. Disorders of potassium homeostasis: hypokalemia and hyperkalemia. *Crit Care Clin*. 2002;18:273-288.
8. Jacobi J, Bircher N, Krinsley J, et al. Guidelines for the use of an insulin infusion for the management of hyperglycemia in critically ill patients. *Crit Care Med*. 2012;40:3251-3276.
9. Kamel KS, Wei C. Controversial issues in the treatment of hyperkalemia. *Nephrol Dial Transplant*. 2003;18:2215-2218.
10. Noronha JL, Matuschak GM. Magnesium in critical illness: metabolism, assessment, and treatment. *Intensive Care Med*. 2002;28:667-679.
11. Tzamaloukas AH, Malhotra D, Rosen BH, et al. Principles of management of severe hyponatremia. *J Am Heart Assoc*. 2013;2(1):e005199. Available at: http://jaha.ahajournals.org/content/2/1/e005199.long. Accessed October 5, 2015.
12. Verbalis JG, Goldsmith SR, Greenberg A, et al. Hyponatremia treatment guidelines 2007: expert panel recommendations. *Am J Med*. 2007;120:S1-S21.

Suggested Website

Society Critical Care Medicine. http://www.SCCM.org/Guidelines

Chapter 18

MANAGEMENT OF SPECIAL POPULATIONS

✓ Objectives

- Review the epidemiology, risk factors, classification, and treatment of pulmonary embolism.
- Recognize the risk factors for venous thromboembolism (VTE).
- Review ICU management and complications related to patients undergoing bariatric surgery.
- Review postoperative management and complications in organ-specific transplant patients.
- Understand the risks and benefits of immunosuppressive therapy, as well as vital adverse effects of immunosuppressive drugs and drug-drug interactions.

Case Study

A morbidly obese 56-year-old man presents with progressive shortness of breath at rest and fatigue 2 days after undergoing a laparoscopic Roux-en-Y gastric bypass complicated by significant intraoperative splenic bleeding. While walking in the hall, the patient had a worsening of shortness of breath and loss of consciousness. The patient regained consciousness. Examination revealed tachycardia and his SpO_2 was noted to be decreased at 88% on room air. Past medical history was unremarkable, and social history revealed him to be a nonsmoker with no substance abuse. The physical examination was consistent with sinus tachycardia, tachypnea, and stable blood pressure. Additional physical examination findings were unremarkable except for serosanguinous drainage from a surgical drain in the left upper quadrant. The patient became more dyspneic and desaturated and required 100% supplemental oxygen. Serum troponin was elevated at 1.14ng/mL, as was the proBNP at 1144 ng/mL. A venous Doppler scan was positive for deep vein thrombosis in the left common femoral vein. The patient was started on an unfractionated heparin drip after the calculated bolus. An attempt for catheter-directed intervention to extract the right atrial thrombus and intrapulmonary artery thrombolysis was aborted because of the presence of patent ductus arteriosus. Twelve hours after achieving therapeutic anticoagulation, the nursing staff noted an increasing amount of blood coming from the surgical drain.

- Is this finding concerning?
- Would it change the approach to this patient?
- What are your alternative options?

I. INTRODUCTION

Certain populations of surgical patients are more prone to specific complications or have unique problems due to the type of surgery performed. Although all surgical patients can develop venous thromboembolism, populations such as the morbidly obese are at higher risk. The morbidly obese patient, the post-operative bariatric surgery patient and the solid organ transplant patient are all susceptible to distinct problems that if missed can cause increased morbidity and mortality.

II. PULMONARY EMBOLISM (PE)

A. Epidemiology/Incidence

Venous thromboembolism (VTE) is the third most common cardiovascular disorder after myocardial infarction and stroke. VTE is a common disease with an incidence of approximately 0.5 to 1.5 per 1000 per year inhabitants. The incidence of nonfatal VTE in the United States is nearly 900,000 events occurring annually. Reported incidence rates for PE ± deep vein thrombosis (DVT) and leg DVT alone range from 29 to 78 and 45 to 117 per 100,000 person-years, respectively (51.4% DVT, 28.2% PE, and 20.5% PE+DVT). The total annual number of VTE remains underestimated because certain percentages of acute pulmonary emboli remain undiagnosed and not suspected until after patient death. Silent PE develops in about 40% to 50% of patients with DVT. Overall, VTE incidence may be higher in African Americans and lower in Asians and Native Americans. The overall age-adjusted incidence rate is higher for men (130 per 100,000) than women (110 per 100,000; male:female sex ratio is 1.2:1). The incidence increases among both sexes with age.

Approximately one-half are related to a current or recent hospitalization. VTE attack rates (2005– 2010) did not change despite near universal in-hospital VTE prophylaxis, possibly the result of short prophylaxis duration. It is reported that the median duration of hospitalization was 3 days, and the median duration of in-hospital prophylaxis was 70 hours. A total of 75% of VTE events occurred after hospital discharge, with a 19.5-day median time to VTE.

The incidence of recurrent VTE is 33% within the first 10 years from the initial episode, with the peak incidence within the first 6 to 12 months. Distribution by recurrent VTE event type was DVT 57.4%, PE 26.4%, and PE+DVT 16.2%. Independent predictors of recurrence include increasing patient age, body mass index (per 10 kg/m2), male sex, active cancer, neurologic disease with leg paresis, thrombophilia, persistent elevated D-dimer among patients with unprovoked or idiopathic VTE, and possibly residual vein thrombosis (**Table 18-1**). Several reversible factors are associated with reduced risk of recurrence of VTE among women, such as pregnancy or the postpartum state, oral contraceptive use, hormone therapy, and gynecologic surgery.

Table 18-1 Independent Risk Factors for Increased Mortality from VTE

Increasing age
Male sex
Low body mass index
Surgical procedures
Trauma
Congestive heart failure
Hospital or nursing home confinement
Chronic lung disease
Active malignancy
Central venous catheters
Transvenous pacemaker
Varicose veins
Prior superficial phlebitis
Neurologic disease with paresis

VTE carries a high mortality. The mortality rate for acute PE exceeds 15% in the first 3 months after diagnosis and surpasses that of myocardial infarction. The Centers for Disease Control (CDC) reported approximately 600,000 to 1,000,000 PE-related deaths per year in the United States. The incidence of sudden death as the presentation of PE is 25%. The risk of early death among PE patients is 18-fold higher compared with patients with DVT alone (**Table 18-2**). PE is an independent predictor of mortality for up to 3 months from the initial event. Survivors of PE are at risk for chronic thromboembolic pulmonary hypertension. High mortality could be related to low clinical suspicion, failure to identify the high-risk population, inadequate prophylaxis, missed diagnosis of severe PE, and insufficient therapy.

Provoked VTE indicates that there was an identifiable risk factor for the VTE; on the contrary, unprovoked VTE indicates that there was no risk factor identified.

Table 18-2 Predictor Factors for Reduced Survival from PE at Time of Presentation

Syncope

Right heart failure

Atrial fibrillation

Elevated cardiac biomarkers

Echocardiographic findings

B. Risk

The risk of thromboembolism among surgical patients is either surgery or patient-related (**Table 18-3**). Surgery-related factors include infection, mobilization, dehydration, and duration and type of surgery. Colorectal surgery had the highest incidence of a thromboembolic event compared with other abdominal surgeries. The incidence of VTE with minor abdominal surgery is relatively low, on average 0.1% to 0.6%. Conversely, major abdominal surgery carries a high risk of 0.8% to 1.7%. Laparoscopic surgery carries a low risk for DVT of 0.03% and 0.02% for fatal PE. Obese patients who undergo bariatric surgery have traditionally been categorized as a high risk for VTE, with PE being one of the most common causes of postoperative death. It is important to mention that these are the non-lower extremities orthopedic, non-oncologic, or trauma surgeries, which usually carry the highest risk of VTE in the postoperative period. Duration of surgery for more than 3.5 hours carries a high risk for thromboembolic events regardless of the type of anesthesia. General anesthesia is associated with a higher risk for DVT than spinal or epidural anesthesia.

Table 18-3 Patient-Related Risk Factors for VTE

- Old age
- Body mass index
- Major surgery
- Recent hospitalization
- Previous history of VTE
- Central venous catheters
- Trauma
- Fractures
- Active cancer
- Superficial vein thrombosis
- Oral contraceptives
- Smoking history
- Varicose veins
- Neurologic disease
- Thrombophilia
- Chronic liver disease
- Pregnancy
- Poor ASA class

Abbreviation: ASA, American Society of Anesthesiologists

Hospitalization for medical illness and hospitalization for surgery account for almost equal proportions of VTE (22% and 24%, respectively). Active cancer accounts for nearly 20% of all incidents of VTE. The risk appears to be higher for patients with cancer of the brain, pancreas, ovary, colon, stomach, lung, kidney, and bone, and in patients with distant metastases.

C. Classification

Pulmonary embolus is classified based on angiographic thrombus burden, hemodynamic effect, right ventricular (RV) strain, and pulmonary hypertension. The clinical classification reflects the severity of the pulmonary emboli and the associated in-hospital or 30-day related mortality risk. The classification has significant implication in the diagnostic and therapeutic interventions and includes:

- Massive pulmonary emboli
- Submassive pulmonary emboli
- Low-risk pulmonary emboli

Massive pulmonary emboli are defined as acute PE with:

- Sustained hypotension (systolic blood pressure 90 mm Hg for at least 15 minutes or requiring inotropic support)
- Shock not due to a cause other than PE

- Arrhythmia
- Hypovolemia
- Sepsis
- Left ventricular (LV) dysfunction
- Pulselessness
- Persistent profound bradycardia (heart rate 40 beats/min with signs or symptoms of shock)

Massive PE carries a high 90-day mortality rate for patients with acute PE and systolic blood pressure 90 mm Hg at presentation. Risk of death is estimated to be 30% to 50%.

Submassive PE is defined as hemodynamically stable PE with RV dysfunction detected on physical examination, electrocardiography, cardiac biomarkers, echocardiography, and chest computed tomography (CT). It is further subdivided into low-intermediate and high-intermediate risk depending on evidence of signs of RV dysfunction and cardiac biomarkers. Either one or none will be present in low-risk intermediate submassive pulmonary emboli. It carries a 15% to 20% 30-day mortality.

Low-risk PE carries a low mortality with an average of ≤1%. It still has significant rates of morbidity and mortality that are functions of older age and comorbidities. It is defined as an acute PE in a normotensive patient with normal biomarker levels and no evidence of RV dysfunction on imaging.

D. Diagnosis

1. Clinical Picture

A high clinical suspicion of PE is essential to properly diagnose PE in a timely fashion because the clinical signs and symptoms are nonspecific. PE can be an incidental finding on radiologic imaging or at autopsy. The clinical signs and symptoms of confirmed PE are:

- Dyspnea 50%

- Pleuritic chest pain 39%
- Substernal chest pain 39%
- Signs of DVT 24%
- Cough 23%
- Fever 10%
- Hemoptysis 8%
- Syncope 6%
- Unilateral leg pain 6%

The physical examination is often unremarkable. Hypoxemia is present in only 60% of the patients, and $PaCO_2$ can be normal, decreased, or elevated. Hypercapnia is often present in patients with limited pulmonary reserve. Alveolar-arterial oxygen gradient is normal in 20%.

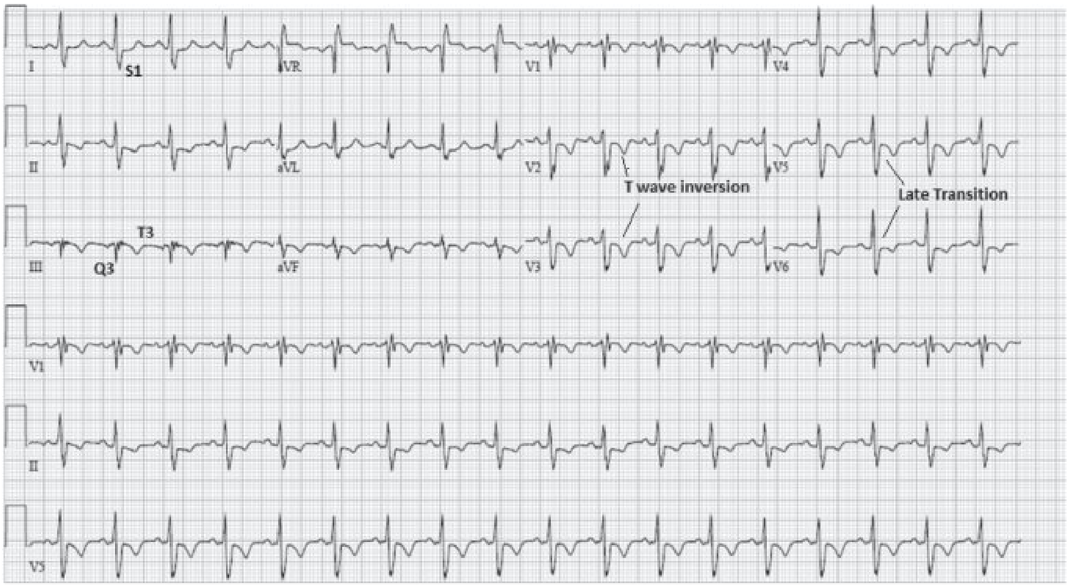
The chest radiographic findings are neither sensitive nor specific for PE.

2. Electrocardiogram

Electrocardiogram (ECG) patterns suggestive of PE and indicative of RV strain are (**Figure 18-1**):

- New right bundle-branch block
- S wave in lead I, Q wave in lead III, or an inverted T wave in lead III
- New T-wave inversion in leads V1 through V4
- New-onset atrial fibrillation

Figure 18-1. ECG Pattern Suggestive of Pulmonary Emboli


I
S1
aVR
V1
V4
II
aVL
V2
V5
T wave inversion
Late Transition
T3
III
Q3
aVF
V3
V6
V1
II
V5

Sinus tachycardia, S1T3Q3, T inversion in V1-3, and late transition in lateral leads. Image courtesy of Bushra Mina, MD

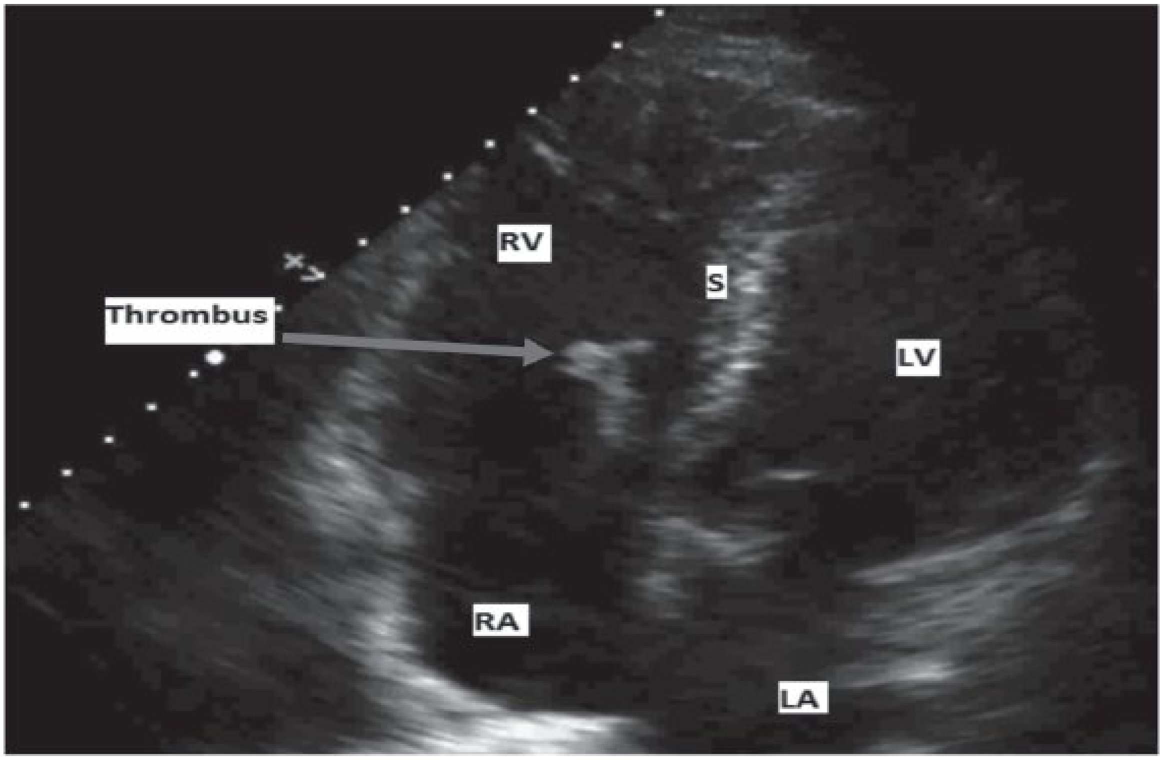
3. Echocardiography

Echocardiography is essential in the assessment of PE severity. Echocardiographic findings in submassive and massive pulmonary emboli are (**Figure 18-2**):

- RV dilatation and hypokinesis
- The ratio of the RV end-diastolic area to the LV diastolic area exceeds the upper level of normal (0.6)
- Interventricular septal flattening with paradoxical septal motion
- Tricuspid regurgitation and evidence of pulmonary hypertension
- Diastolic LV impairment with a small difference between the LV area during diastole and systole

- McConnell sign (akinesia of the mid RV free wall and hyperkinesia of the apical wall)
- Lack of collapse of the inferior vena cava during inspiration

Figure 18-2. Echocardiographic Findings of Submassive and Massive PE



ECHO revealed dilatation of both the right atrium and ventricle with bulging of the interventricular septum into the left ventricle. There is a thrombus on the tricuspid valve. Image courtesy of Bushra Mina, MD

4. Biomarkers

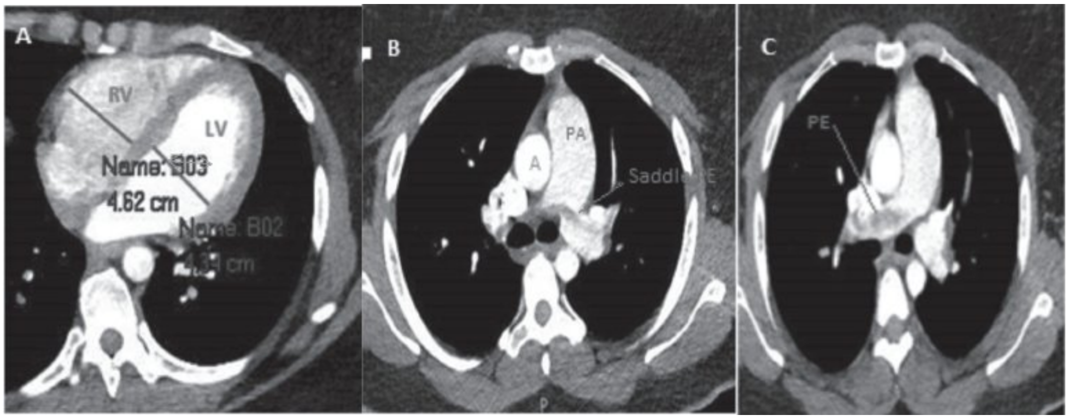
Biomarkers of myocardial injury and dysfunction have a prognostic factor. Elevated troponin I and T were associated with 4.26-fold increased odds of overall mortality. Elevated brain natriuretic peptide (BNP) and N-terminal pro-BNP (> 6 ng/mL) have odds ratios for short-term mortality of 9.51 (95% CI:

3.16 to 28.64) and 5.74 (95% CI: 2.18 to 15.13), respectively. The odds of mortality from PE are increased with a combination of markers. Elevated troponin and NT-pro-BNP were found to stratify normotensive patients with PE more accurately with PE-related 30-day mortality exceeding 30%. A combination of cardiac troponin I 0.1 ng/L and RV/LV 0.9 on echocardiography identified a subgroup with an all-cause 30-day mortality of 38%.

5. Radiographic Studies

CT scan angiography is the modality of choice for confirming the diagnosis of PE (**Figure 18-3**). In patients with a low or intermediate clinical probability of PE, a negative CT had a high negative predictive value for PE (96% and 89%, respectively), whereas this was only 60% in those with a high pre-test probability. Conversely, the positive predictive value of a positive CT was high (92% to 96%) in patients with an intermediate or high clinical probability, but much lower (58%) in patients with a low pre-test likelihood of PE.

Figure 18-3. Computed Tomography Scan of Chest with IV Contrast



A. RV dilated with RV:LV ratio >1 with bowing of the interventricular septum into the left ventricle. B. Dilatation of the pulmonary artery diameter with increase in the PA:ascending aorta ratio. C. Saddle embolus into the right main pulmonary arteries.
Image courtesy of Bushra Mina, MD

CT scan angiography is the modality of choice for confirming the diagnosis of PE.

!

The size of the pulmonary artery in comparison with the ascending aorta is indicative of underlying pulmonary hypertension. That dilatation of the RV in contrast to the LV with an RV/LV ratio of ≥ 1 with deviation of the interventricular septum to the left is indicative of RV strain and has a poor prognostic implication.

6. Scoring System

Clinical scores can predict the probability and adverse outcomes/severity independent of imaging or biomarker. Wells score (**Table 18-4**), Revised Geneva score, and pulmonary embolism severity index (PESI/simplified PESI scores) (**Table 18-5**) are validated clinical prediction scores to aid in the assessment of the clinical probability of underlying PE.

Table 18-4 Simplified Wells Score

Variable	**Score**
Clinical signs of DVT	3
Alternative diagnosis less likely than PE	3
Previous PE or DVT	1.5
Heart rate >100 beats/min	1.5
Surgery or immobilization within 4 weeks	1.5
Hemoptysis	1
Active cancer	1
Clinical Probability	
PE unlikely	≤4
PE likely	≥4

Table 18-5 Simplified PESI Score

Parameter	Simplified PESI Score
Age	1 point if age >80
Cancer	1 point
Chronic heart failure Chronic pulmonary disease	1 point
Heart rate >110 beats/min	1 point
Systolic blood pressure <100 mm Hg	1 point
Arterial oxygen saturation < 90%	1 point
	0 points = 30 days mortality risk 1.0% (95% CI: 0.0%–2.1%)
	≥ 1 point = 30 days mortality risk 10.9% (95% CI: 8.5%–13.2%)

Abbreviation: PESI, pulmonary embolism severity index

E. Treatment

1. Segmental and Subsegmental Pulmonary Embolism

Treatment strategies depend on the hemodynamic effect of PE. For PE without shock or any evidence of RV strain, such as in cases on segmental and subsegmental PE, treatment consists of anticoagulation either with unfractionated heparin (UFH) or low-molecular-weight heparin (LMWH) with conversion to oral anticoagulation either with warfarin or non-vitamin K-dependent direct oral anticoagulants (DOACs). No evidence suggests that bed rest has any beneficial effect on these patients' clinical outcomes.

New evidence supports the outpatient treatment of segmental or subsegmental hemodynamic stable PE with DOACs. The duration of therapy for provoked PE is 3 months and unprovoked is 6 months. Treatment for a more extended period is not recommended, providing that the underlying risk no longer exists.

2. Submassive Pulmonary Embolism

Treatment of intermediate low-risk submassive PE is hospitalization and anticoagulation with UFH or LMWH with consideration for early discharge on oral agents. Existing evidence does not support primary reperfusion treatment either with catheter-directed intervention or systemic thrombolysis. The duration of anticoagulation is 3 months in provoked PE and 6 months for unprovoked PE.

Treatment of intermediate high-risk submassive PE is anticoagulation and consideration for rescue reperfusion. Full-dose systemic thrombolysis should be considered if there are signs of hemodynamic decompensation. Catheter-directed intervention or surgical pulmonary embolectomy are alternative rescue interventions, especially if there is a bleeding risk or contraindications for systemic thrombolysis (**Table 18-6**). The duration of treatment is a total of 3 months, but an extended period might be recommended.

Table 18-6 Contraindications for Systemic Thrombolytics

Absolute contraindications

- Hemorrhagic stroke or stroke of unknown origin at any time
- Ischemic stroke in preceding 6 months
- Central nervous system damage or neoplasms
- Recent major trauma/surgery/head injury (within preceding 3 weeks)
- Gastrointestinal bleeding within the last month
- Known bleeding

Relative contraindications

- Transient ischemic attack in preceding 6 months
- Oral anticoagulant therapy
- Pregnancy or within 1 week postpartum
- Non-compressible punctures
- Traumatic resuscitation
- Refractory hypertension (systolic blood pressure 180 mm Hg)
- Advanced liver disease
- Infective endocarditis
- Active peptic ulcer

Approved thrombolytics are:

- Streptokinase 250,000 IU as a loading dose over 30 min, followed by 100,000 IU/h over 12–24 h or accelerated regimen: 1.5 million IU over 2 h
- Urokinase 4400 IU/kg as a loading dose over 10 min, followed by 4400 IU/kg/h over 12–24 h or accelerated regimen: 3 million IU over 2 h

- rtPA 100 mg over 2 h or 0.6 mg/kg over 15 min (maximum dose 50 mg)

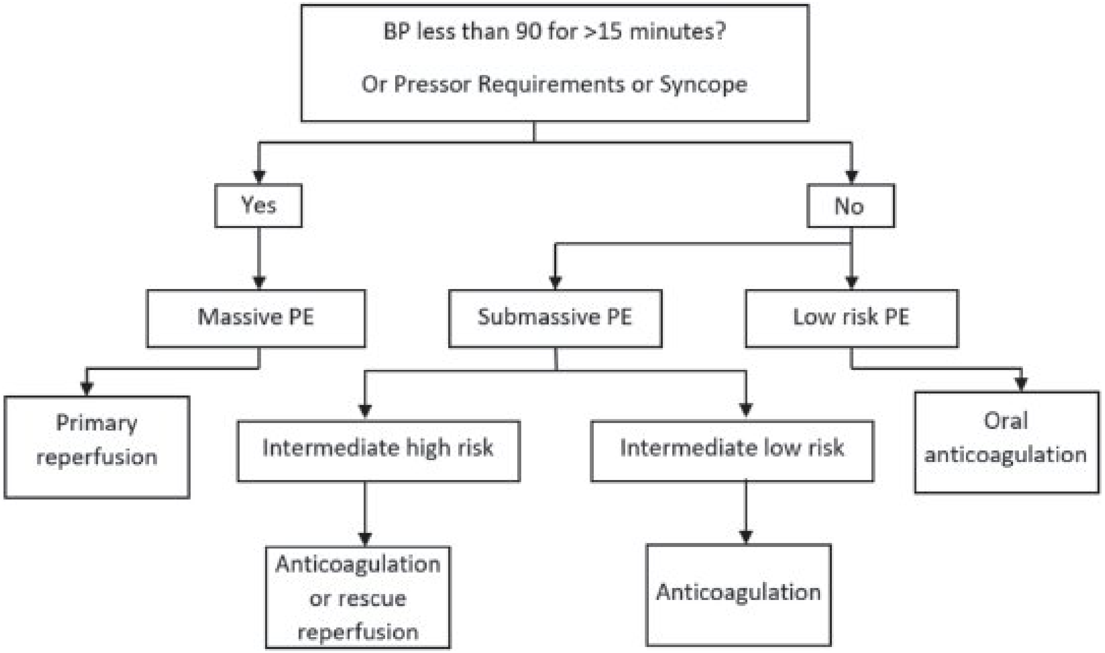
3. Massive Pulmonary Embolism

> !
>
> *Hemodynamic support and mechanical ventilation are indicated in the initial management of massive PE.*
>
> !

Treatment of massive PE requires a multidisciplinary team approach. Patients are admitted to intensive care units (ICU). Hemodynamic support and mechanical ventilation are indicated in the initial management of massive PE. Patients will require vasopressors to maintain adequate blood pressure and tissue perfusion. Inotropic support might be necessary for acute right heart failure. Primary reperfusion should be initiated urgently. Primary reperfusion treatment, mainly systemic thrombolysis, is the treatment of choice. Intravenous UFH should be administered to these patients as the preferred mode of initial anticoagulation. Catheter-directed intervention should be an option in experienced centers. Extracorporeal membrane oxygenation (ECMO) might be required. Surgical pulmonary embolectomy is indicated if systemic thrombolysis is contraindicated or fails to stabilize the hemodynamic status.

Treatment for unprovoked PE is indefinite after the first 3 months of treatment, depending on the risk factors and bleeding risks. In these patients, periodic reassessment based on the risk of thromboembolic event and bleeding risk for the withdrawal of anticoagulant treatment is recommended (**Figure 18-4**).

Figure 18-4. Treatment Algorithm for Pulmonary Emboli


BP less than 90 for >15 minutes?
Or Pressor Requirements or Syncope
Yes
No
Massive PE
Submassive PE
Low risk PE
Primary reperfusion
Intermediate high risk
Intermediate low risk
Oral anticoagulation
Anticoagulation or rescue reperfusion
Anticoagulation

Inferior vena cava filters are recommended if anticoagulation is contraindicated or there is recurrence of VTE despite proper anticoagulation. The retrievable filter should be removed once anticoagulation is initiated. The incidence of late complications of retrievable filters is 10% as a result of filter migration, tilting or deformation, penetration of the cava wall by filter limbs, the fracturing of the filter and embolization of fragments, and thrombosis of the device.

The recurrence rate of VTE after discontinuation of treatment is approximately 2.5% per year after provoked PE compared with 4.5% per year after unprovoked PE. Recurrence rates may be higher, up to 10%, in the first year after withdrawal of anticoagulant treatment.

F. Prophylaxis

Prophylaxis is indicated for surgical patients with the encouragement of early mobility. Bimodal prophylaxis is indicated in high-risk patients with pharmacologic and mechanical agents. Pharmacologic agents include low-dose unfractionated heparin, LMWH, fondaparinux, adjusted-dose vitamin K antagonist, and aspirin. Apixaban, dabigatran, or rivaroxaban can be an alternative. An intermittent pneumatic compression device (IPCD) is indicated in all patients. Risk stratification for VTE is based on both patient- and procedure-specific risk factors. Specific models for risk stratification exist, such as Rogers and Cabrini scores. The American College of Chest Physicians published (Antithrombotic Therapy and Prevention of Thrombosis, 9th ed: Evidence-Based Clinical Practice Guidelines) recommendations for VTE prophylaxis in surgical patients (**Table 18-7**, **Table 18-8**). All bariatric surgery patients are at risk of VTE, with 30% of postoperative death due to PE. Bariatric patients will have at least a Caprini score of at least four and, therefore, be at least at moderate risk or higher. Low-dose aspirin or fondaparinux can substitute LMWH or low-dose unfractionated heparin if heparin is contraindicated. It is not recommended to use inferior vena cava filters as primary prophylaxis. Also, periodic venous ultrasonography surveillance is not recommended. VTE prophylaxis regimes are listed in **Table 18-9**.

Table 18-7 VTE Prophylaxis in Abdominal and Pelvic Surgical Patients

For general and abdominal-pelvic surgery patients	Mode of Prophylaxis
Very low risk for VTE (< 0.5%; Rogers score, < 7; Caprini score, 0)	Early ambulation.
Low risk for VTE (~1.5%; Rogers score, 7–10; Caprini score, 1–2)	Mechanical prophylaxis, preferably IPC
Moderate risk for VTE (~3.0%; Rogers score, > 10; Caprini score, 3–4)	
• No risk of major bleeding	LMWH, LDUH, or IPC
• Risk of major bleeding	IPC
High risk for VTE (~6.0% Rogers score; Caprini score, ≥ 5)	
• No risk for major bleeding	LMWH, LDUH, or IPC
• Risk for major bleeding	IPC

Abbreviations: LMWH, low-molecular-weight heparin; LDUH, low-dose unfractionated heparin; IPC, intermittent pneumatic compression.

Table 18-8 VTE Prophylaxis in Trauma Patients

Trauma Patients	Mode of Prophylaxis
Major trauma	LMWH, LDUH, or IPC
High risk for VTE (including those with acute spinal cord injury, traumatic brain injury, and spinal surgery for trauma)	IPC when not contraindicated by lower extremity injury
Patients with major bleeding in whom LMWH and LDUH are contraindicated	IPC when not contraindicated by lower extremity injury. Add LMWH or LDUH when the risk of bleeding diminishes or no contraindication

Abbreviations: LMWH, low-molecular-weight heparin; LDUH, low-dose unfractionated heparin; IPC, intermittent pneumatic compression.

Table 18-9 Prophylaxis Regimens in Surgical Patients

Drug	Dose Recommended (Normal Cr Cl)
Unfractionated heparin	5000 units SQ Q 8–12 hours
Enoxaparin	40 mg SQ daily or 30 mg SQ Q 12 hours
Dalteparin	5000 units SQ daily
Fondaparinux	2.5 mg SQ QD

Abbreviation: Cr CI, Creatinine clearance

VTE prophylaxis should be initiated 2 hours postoperatively except when contraindicated. In spinal and neurosurgical procedures, postoperative chemoprophylaxis is often delayed 24–48 hours. The duration of prophylaxis is 7–10 days and can extend up to 12 days. An extended period of prophylaxis is indicated if risk factors persist. VTE prophylaxis should be discontinued temporarily for certain surgical procedures or other invasive interventions. LMWH can be discontinued 12 hours before the procedure and can be restarted 2 hours postoperatively and after removal of epidural catheters.

III. ICU MANAGEMENT OF THE BARIATRIC SURGERY PATIENT

Case Study

A 61-year-old woman with morbid obesity (BMI 43) is admitted with severe community-acquired pneumonia. Medical history includes diabetes mellitus, essential hypertension, obstructive sleep apnea, and hypercholesterolemia. Surgical history includes biliopancreatic bypass, caesarean section, and carpal tunnel release. Preoperative medication included metformin 500 mg daily, atenolol 25 mg daily, and rosuvastatin 10 mg daily. The patient uses BiPAP at bedtime. Of note, since her bariatric surgery 9 months ago, she has lost 90 lb.

– How would the patient's morbid obesity or a history of bariatric surgery change the approach to this patient?

A. Treatment

To provide high-quality care for the bariatric surgery patient, it is crucial to have the staff trained in caring for these patients and for the facility to have the necessary appropriate equipment. Standard equipment such as beds, stretchers, wheelchairs, blood pressure (BP) cuffs, IV catheters, as well as imaging devices (CT/MRI scanners) may not accommodate these patients. ICU admission criteria include:

- Body mass index (BMI) greater than 60
- A requirement for continuous cardiac monitoring
- Severe obstructive sleep apnea (OSA)
- Refractory diabetes mellitus
- Intraoperative complication, ie, bleeding, cardiac or respiratory event

1. Cardiac/Hemodynamic Monitoring

The indication for the use of invasive catheters (central venous catheters, arterial lines) is the same as the non-bariatric surgical patient. Because of altered anatomy, placement of central catheters should be performed with ultrasound guidance. The length of standard central catheters and needles may not be adequate (**Figure 18-5**). Noninvasive BP cuffs should be of the appropriate size. There can be a spurious elevation of 10–50 mm Hg systolic if the cuff is too small.

Figure 18-5. Inadequate Length of Central Venous Catheter in Morbidly Obese Patient

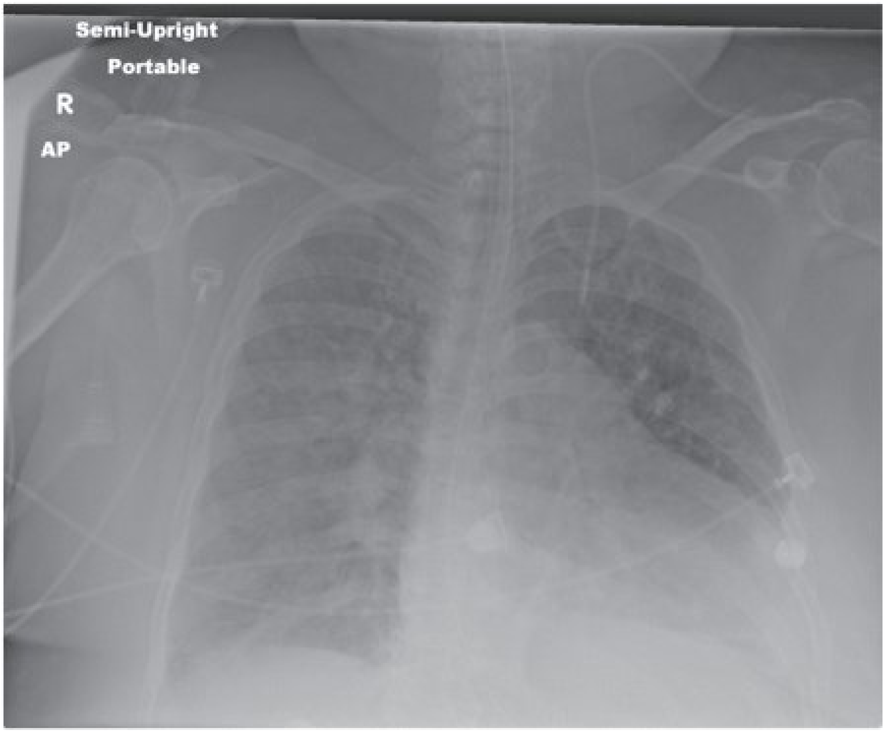


Image courtesy of Mary Jane Reed, MD

Vascular access via two peripheral lines is usually adequate. If the ICU stay is extended, a dual lumen peripherally inserted central cathether is recommended.

2. Respiratory

Bariatric patients are at high risk for pulmonary complications because of the high incidence of OSA or obesity hypoventilation syndrome (OHS), which can be present in up to 70% of bariatric surgery patients. These patients also have a small diameter upper airway. Pulmonary compliance is reduced as a result of a non-compliant chest wall and restrictive lung disease because of truncal obesity. When mechanical ventilation is required, the tidal volume should be 6–8 mL/kg ideal body weight (IBW). Plateau pressures need to be maintained below 30 cm H_2O if possible. Increasing positive end-expiratory pressure (PEEP) will improve compliance in part by increased recruitment and decreasing atelectasis. Starting with 10 cm H_2O of PEEP in an obese patient may prevent atelectrauma.

Extubation should be provided as soon as appropriate. The difficulty of intubation should be noted before extubation. Extubation to noninvasive positive-pressure ventilation (NIPPV) can reduce reintubation rates.

Noninvasive ventilation (NIV) can be used effectively in these patients. No evidence exists that positive pressure ventilation from NIV increases the risk of leakage from the anastomosis site. If patients use NIV at home, they should be encouraged to bring their device to the hospital, unless oxygen supplementation is required. This improves comfort and effectiveness compared with hospital-provided units.

Early tracheostomy is recommended if intubation and the need for mechanical ventilation are expected to be prolonged. This improves patient comfort and may reduce complications from prolonged intubation. Expertise in tracheostomy in the morbidly obese is helpful because redundant tissue and thick adipose tissue may overlie the trachea, requiring submental panniculectomy and specialized tracheotomy tubes.

3. Nutrition

!

Critically ill post-bariatric surgery patients should receive thiamine and folate before glucose.

!

Most patients begin an oral diet the day or evening of bariatric surgery. Patients with significant delay of appropriate enteral nutrition should have parenteral nutrition begun. Nutritional deficiency is common among bariatric surgery patients because of malabsorption, and adequate dietary supplementation is required. Micronutrient deficiencies often present in patients who have had malabsorption surgery and significant weight loss. Ensuring that these patients have thiamine and folate before significant amounts of glucose should be considered because Wernicke's-like syndrome has been described in these patients. Other micronutrients such as copper, vitamin D, and zinc may also be deficient. B12 levels should also be obtained.

4. Analgesia

Pain assessment scales should guide the goal of pain management. Pain management should be according to a protocol-based approach with a stepwise approach. Opiates should be avoided because of the risk of respiratory depression, delirium, ileus, and immunosuppression. Epidural analgesia, as well as the use of acetaminophen and ketamine, could be adjunct to opioids. Neuropathic pain medication, such as gabapentin, can be used. Avoid NSAIDs because of their risk profile and association with marginal ulceration of anastomosis.

5. Glycemic Control

Glycemic control in critically ill postoperative patients has been well studied. The optimal glucose control level is 140–180 mg/dL and not below 70 mg/dL. Many bariatric patients postoperatively require less insulin than prior to surgery as a result of weight loss, decreased oral intake, and change in insulin resistance.

6. Medication Dosing

Bariatric patients have a large volume of distribution for lipophilic drugs and increased clearance of hydrophilic drugs. This finding requires adjusting the doses of commonly used medications in the ICU. Drugs are dosed based on ideal body weight (IBW), total body weight (TBW), or dosing weight (DW), sometimes referred to as adjusted body weight (ABW).

> *Up to a 30% higher dose of enoxaparin may be needed for prophylaxis in the morbidly obese patient, but the ideal dose is unknown.*

IBW is used to calculate digoxin, beta-blockers, penicillins, cephalosporins, acyclovir, glucocorticoids, H2 blockers, atracurium, vecuronium, fentanyl, midazolam, lorazepam, morphine sulfate, and phenytoin. TBW is used to calculate the dose of succinylcholine, heparin, enoxaparin, and vancomycin. DW is used to calculate the dose of aminoglycosides.

B. Complications of Bariatric Surgery

To address and treat the complications associated with bariatric surgery, one should understand that this field is a dynamic one, and the procedures, instruments, techniques, and technology are continually changing. There are two categories of procedures: volume restrictive and nutrient malabsorptive procedures (**Table 18-10**, **18-11**, **18-12**).

Table 18-10 Postoperative Complications of Bariatric Surgery

Perioperative Complications	Late Complications
Anastomotic leak (1%)	Anastomotic stricture (3%–12%)
Gastrointestinal bleeding (2.5%)	Marginal ulcer (0.5%–20%)
Trocar injury (0.1%)	Bowel obstruction (2.5%)
Deep vein thrombosis (1%)	Incisional hernia (0.5%–8%)
Pulmonary embolism (0.5%)	Internal hernia (1%–3%)
Bowel obstruction (1.7%)	Dumping syndrome (up to 30%)
Wound infection (3%)	Cholecystitis (up to 30%)
Pneumonia (0.2%)	
Cardiac event mortality (0.2%–1%) Intraoperative splenic injury in 0.41%	

Table 18-11 Laparoscopic Gastric Banding Complications

Early Complications	Late Complications
Incidence: 13%	6%–25%
Preoperative mortality: 0.07%	
Postoperative mortality: 0.21%	
Reoperation rate: High	Reoperation rate: 10–50%
Type Intractable vomiting Gastroesophageal perforation Improper band positioning Early postoperative band slippage requiring repositioning Acute stomal obstruction Band infection Bleeding	**Type** Band slippage with or without pouch dilation (4%–12.5%) Band erosion (2.8%) Esophageal dilation (5%–71%) Failure to lose weight or to maintain weight loss (2%–5%) Worsening GERD 13%–39% Esophagitis 75%

Table 18-12 Sleeve Gastrectomy (SG) Complications

Complications	Incidence
Preoperative mortality	0.29%
Postoperative mortality	0.34%
Gastroesophageal reflux	23%
Vomiting	18%
Difficult-to-remedy proximal leaks	4.9%
Bleeding from the long gastric staple line	2.4%
Incisional hernia	2.4%
Stenosis/stricture	2.4%
Leak	2.4%
Gastric tube stricture	2.3%
Nutritional deficiencies	
• Iron	43%
• Vitamin D	39%
• Folic acid	15%
• Vitamin B1	11%
• Vitamin B12	9%

Roux-en-Y Gastric Bypass (RYGB)

RYGB is a restrictive procedure with a malabsorptive component. This procedure has the risk of “dumping syndrome,” which is a constellation of symptoms, including flushing, tachycardia, and weakness (**Figure 18-6**).

Sleeve Gastrectomy (SG)

SG is a restrictive procedure without a malabsorptive component. Leakage and bleeding from a long staple line can occur (**Figure 18-7**).

Biliopancreatic Diversion with Duodenal Switch (BPD/DS)

BPD/DS is a procedure that has both restrictive and malabsorptive properties. There is more malabsorption, especially of protein and fat-soluble vitamins (**Figure 18-8**).

Intragastric Balloon (IGB)

IGB is a purely restrictive tool placed endoscopically. Nausea, vomiting, reflux, balloon migration, perforation of stomach and/or intestine are all known potential complications. Because the balloon is usually filled with blue dye, the presence of urine that is blue should prompt the patient to seek medical attention because the deflated balloon has the potential to migrate and cause an intestinal obstruction.

Gastric Band (GB)

GB is a purely restrictive procedure that has decreased in use in the last decade because results have not been sustainable. Reflux, erosion, and slippage causing obstruction can occur (**Figure 18-9**).

Figure 18-6. RYGB

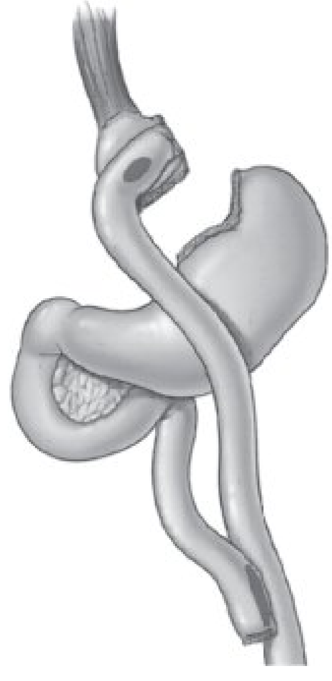


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Figure 18-7. Gastric Sleeve

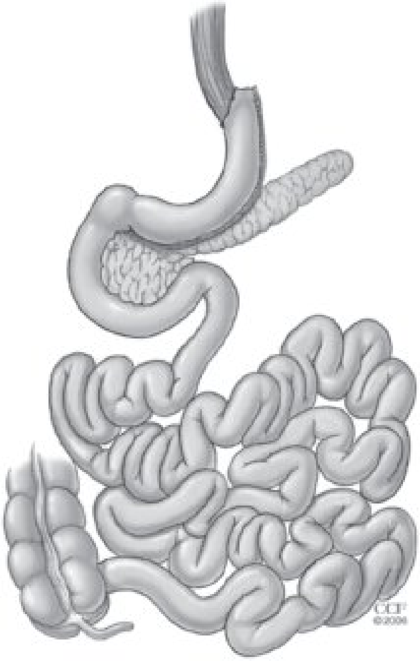

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Figure 18-8. Biliopancreatic Diversion (BPD/DS)

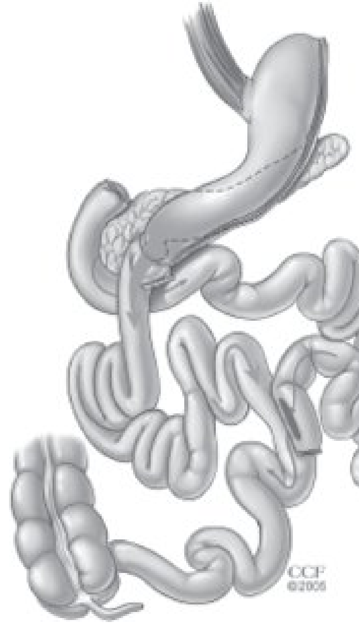

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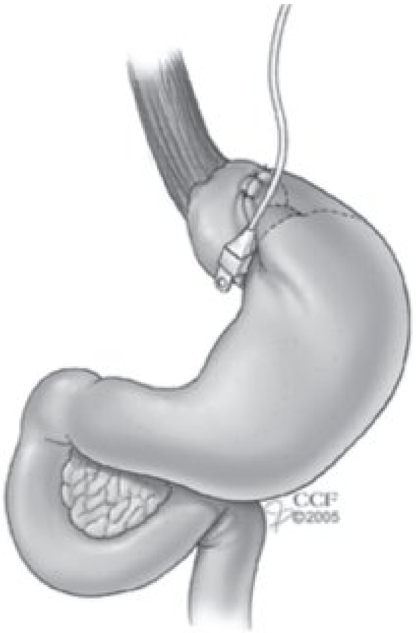
Figure 18-9. Gastric Band



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1. Anastomotic Leak

!

A sustained pulse of 120 beats per minute in the early postoperative bariatric surgery patient should be investigated.

!

Leaks usually occur within 2 weeks of the procedure. The signs and symptoms are often subtle, with a lack of abdominal findings on clinical examination. Typical signs of peritonitis and sepsis may be absent. This lack of clinical findings is, in part, a result of body habitus and pain management. The most common signs are tachypnea and tachycardia. A low-grade fever is also common. These patients are often assessed for PE and or other respiratory complications because of the presenting signs and symptoms. The diagnosis is made after a contrast study or CT scan. If there is difficulty in obtaining an imaging study and there is a high index of suspicion and worsening hemodynamics, reoperation should be performed immediately. The treatment is irrigation, drainage, broad-spectrum antibiotics, and placement of a percutaneous drain and an enteral feeding tube in the OR. Because the diagnosis is often difficult, these patients should undergo CT pulmonary angiography with oral contrast abdominal and pelvic CT.

2. Hemorrhage

Most bleeding occurs at the staple line or anastomosis. This problem is often the result of the inability of the staple line to compress a small vessel. Tachycardia is a common sign followed by melena. Most episodes resolve without the need for intervention. Transfusion of blood products and reversal of anticoagulation is done if needed. If there is an ongoing transfusion requirement, endoscopic evaluation is recommended. If there is hemodynamic instability or bleeding not amenable to endoscopic therapy, surgery is recommended.

3. Venous Thromboembolism

Making the diagnosis of VTE can be difficult. Imaging requires appropriate machines to support the patient's weight. If there is a high suspicion of PE and a delay or inability to obtain an imaging study, anticoagulation should be started immediately. This is usually done with heparin since it can be stopped, and the anticoagulation effect dissipates quickly if bleeding occurs. If there is a contraindication to anticoagulation, an IVC filter should be placed to decrease the risk of further clot embolization. Risk factors for VTE and PE are included in **Table 18-13**.

Table 18-13 Risk Factors for VTE and Fatal PE

Risk Factors for VTE

- BMI greater than 50
- Previous history of VTE
- Pulmonary hypertension
- Poor functional status
- Open or revision procedure
- Surgical time of greater than 3 hours

Risk Factors for Fatal PE

- BMI greater than 60
- Obesity hypoventilation syndrome
- Revision surgery

4. Acute Myocardial Infarction (MI)

The risk of acute MI is approximately 0.2%. The risk increases with a history of coronary artery disease (CAD). Bariatric patients have known risk factors for CAD. Their risk decreases over time after surgery as their comorbidities improve.

5. Respiratory Failure/Pneumonia

The risk for respiratory failure and pneumonia following bariatric surgery is 0.25% to 0.6%. The risk for pneumonia is increased by a history of congestive heart failure, chronic obstructive pulmonary disease (COPD), bleeding disorders, tobacco use, increasing age, and open versus laparoscopic procedure. The risk for respiratory failure is increased in patients with COPD, previous percutaneous coronary intervention, diabetes mellitus, increased age, prolonged anesthesia, and an open versus laparoscopic procedure. Early ambulation, abdominal pain control, and incentive spirometry have been shown to decrease the incidence of respiratory failure.

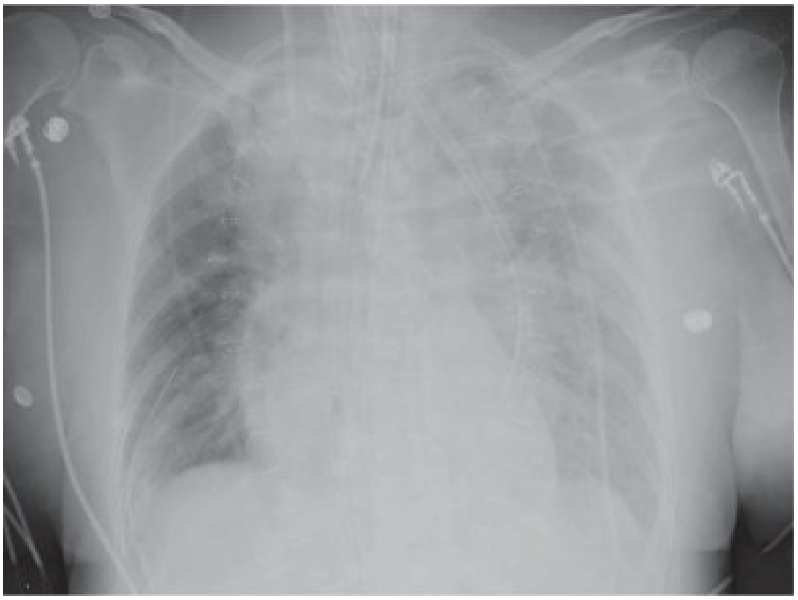
IV. TRANSPLANT ICU

Case Study

A 55-year-old man with a significant history of COPD undergoes bilateral lung transplantation. The donor was cytomegalovirus (CMV) negative, and the recipient is CMV positive. The surgery is performed without the use of cardiopulmonary bypass, no complications, and minimal reported blood loss. The patient is transported to the ICU on mechanical ventilation of volume control with a tidal volume of 6 mL/kg, FIO_2 of 0.7, and PEEP of 8 cm H_2O with an arterial SpO_2 of 95%. The following treatments are initiated via nasogastric tube: prophylactic antimicrobials vancomycin and cefepime, valganciclovir, itraconazole, and immunosuppressive drugs tacrolimus and mycophenolate mofetil. IV methylprednisolone and inhaled amphotericin are administered. The patient's last pulmonary artery occlusion measurement before discontinuation of the pulmonary artery (PA) catheter 4 hours postoperatively was 6 mm Hg. Six hours after surgery, the patient requires increased FIO_2, and peak and plateau pressures on the ventilator have increased. He has developed a low-grade fever of 38°C (100.4°F) but remains hemodynamically stable. A chest radiograph is obtained (**Figure 18-10**).

- Is this finding concerning?
- How does the surgical history change the approach to this patient?

Figure 18-10. Chest Radiograph of COPD Patient Six Hours After Uneventful Bilateral Lung Transplant



A. Diagnosis and Management of Organ-specific Postoperative Complications

Since the 1960s, surgical techniques, as well as immunosuppressive therapy for allograft rejection, have improved in solid organ transplantation. Survival time has increased, and antimicrobial treatment has helped decrease infection. In recent decades, kidney and pancreas transplant patients do not necessarily require a stay in the ICU. However, transplant institutions may still want the recipient to be observed for at least 24 hours. The lung, liver, and heart continue to remain a challenge because of their respiratory and hemodynamic risk intraoperatively and postoperatively. Depending on how these patients do early postoperatively affects their long-term outcome. Recognizing common illnesses and syndromes that come with transplant is vital because missing diagnoses such as infection, acute rejection, or allograft dysfunction can result in death.

1. Heart Transplant

Primary indications for heart transplant include coronary artery disease, valvular heart disease, congenital heart disease, and dilated cardiomyopathy. The median range of survival has reached 11 years. The most common causes of death from heart transplants are allograft rejection, infections, vasculopathy, and malignancies such as lymphoma.

Intraoperatively, a transesophageal echocardiogram is performed. If tricuspid regurgitation (TR) is seen intraoperatively, an echocardiogram within 24 hours is warranted. Depending on the severity of the TR, a donor tricuspid valve may be considered. Pericardial effusions are common postoperatively and are only drained if hemodynamic instability occurs. The transplanted heart cannot respond to hypovolemia with reflex tachycardia because of denervation, so adequate preload is necessary to maintain blood pressure and stroke volume. In conjunction, intravenous fluids are used frugally, and diuresis is aggressively administered intraoperatively and postoperatively. In cases where the left ventricle needs assistance with cardiac output, inotropes such as dobutamine or milrinone are used.

Complications of heart transplant are detailed here.

a. Primary Heart Graft Failure

Primary graft failure accounts for 20% to 40% of deaths in the early postoperatively period. Failure of the graft typically occurs when the demands of the new heart are unable to respond to that of its new circulatory environment. Severe graft failure is described as low cardiac output and high filling pressures.

b. Right Ventricular Failure and Pulmonary Hypertension

Patients who have pulmonary hypertension perioperatively might experience RV failure. Usually, this can be controlled with isoproterenol in reducing RV afterload. If pulmonary hypertension is not resolving and causing hemodynamic instability, intravenous nitroglycerine, nitroprusside, and prostaglandin E1 may be used. A vasopressor might be needed because these agents are potent general vasodilators. Inhaled nitric oxide (iNO) can be used as a selective pulmonary vasodilator, thus reducing intrapulmonary shunting. Sildenafil has also been used in pulmonary hypertension that remains persistent.

c. Left Ventricular Failure

LV failure results from reperfusion injury in patients who have had greater than 5 hours of cold ischemic time. Weeks to years post-transplant, LV failure can result from myocarditis, acute rejection, allograft CAD, and allograft dysfunction.

d. Rejection

In heart transplant patients, rejection is typically asymptomatic, making it challenging for the clinician. Within the first 30 days, there is still a 7% death rate from rejection. Clinical symptoms are nonspecific, including hypotension, fatigue, fever, and congestive heart failure. Endomyocardial biopsies are performed weekly within the first 30 days. In chronic rejection typically months to years later, accelerated CAD will manifest itself clinically presenting as dyspnea. More than 50% of patients develop CAD in 5 years.

2. Lung Transplant

Patients who primarily have COPD and interstitial pulmonary fibrosis (IPF) receive lung transplantation. Patients may receive a single lung transplant or a double lung transplant. Patients with cystic fibrosis receive double lung transplants to avoid the various multidrug-resistant organisms that colonize the native lungs.

Certain factors need to be acknowledged in lung transplant patients.

- Lung-protective ventilation is recommended postoperatively, and high airway pressures should be avoided.
- Patients will have pulmonary artery catheters for evaluation of hypoxia if present.

- Recipients are taken off invasive mechanical ventilation quickly to help decrease ventilator-associated pneumonia.
- Patients with lung transplants also have apical and basal chest tubes. Basal chest tubes remain longer to help relieve ongoing pleural effusions, usually 5 to 7 days.

Fluid management tends to be difficult in lung transplant because patients can have a systemic inflammatory response from cardiopulmonary bypass, primary graft dysfunction, and sepsis. When this occurs, patients will develop noncardiogenic pulmonary edema which remains a challenge for the new lung and also makes it challenging to suppress edema because of disrupted lymphatic drainage. Minimizing fluids postoperatively is recommended.

Complications of lung transplants are detailed here.

a. Primary Graft Dysfunction (PGD)

The International Society of Heart and Lung Transplant (ISHLT) developed a grading system to help identify primary graft dysfunction. The presence of diffuse infiltrates involving the lung allografts are revealed on a postoperative chest radiograph. PaO_2/FIO_2 (P/F ratio) is used to identify the grade of severity: Grade 1 (PF ratio > 300), Grade 2 (PF ratio 200–300), and Grade 3 (PF ratio < 200). Furthermore, other causes of PGD need to be ruled out, such as pneumonia, rejection, cardiogenic pulmonary edema, and pulmonary venous outflow obstruction. The clinician should be aware of ischemic time, donor lung pathology, and time for lung reperfusion because these are major risk factors for PGD.

As mentioned earlier, fluid is generally avoided in lung transplant patients. When PGD is confirmed, a negative fluid balance helps reduce symptoms. In cases of severe hypoxia and PGD, iNO has been used to improve oxygenation; however, no controlled studies have shown any mortality benefit. Furthermore, in PGD that is refractory to invasive mechanical ventilation and iNO, prostaglandin E1 (PGE1) has shown to improve reperfusion injury. Because PGE1 is a nonselective vasodilator, it may hasten a decline in ventilation/perfusion matching in the lung. If therapy continues to show no improvement in PGD, extracorporeal life support (ECLS) is used during this stage of severity.

b. Rejection

Hyperacute rejection rarely occurs because recipient and donor antihuman leukocyte antigen antibodies are performed before transplant. Acute rejection occurs after the first week up to the first year. Clinically, patients have low-grade fevers, negative cultures, perihilar infiltrates, hypoxemia, airway inflammation, and an elevated white blood count. Acute rejection is treated with pulse methylprednisolone 10–15 mg/kg for the first 3 to 5 days and then continued for 2 to 3 weeks with a tapering dose.

c. Bleeding

Even though blood may not be seen in chest tube drainage, a drop in hemoglobin is concerning and remains one of the reasons patients may return to the operating room. Bleeding has not been shown to increase mortality perioperatively.

d. Airway Complications

Bronchial necrosis, endobronchial infections, exophytic excessive granulation tissue formation, tracheobronchomalacia, bronchial fistulas, and bronchial stenosis remain challenging to the clinician. Bronchial necrosis and endobronchial infections can occur earlier in the postoperative period. Necrosis may occur because of the interruption of blood supply from the bronchial artery at the site of anastomosis. The new lung then only relies on blood supply from pulmonary artery collaterals. Clinical findings of bronchial necrosis are persistent air leak, lung collapse, difficult to extubate, subcutaneous emphysema, pneumomediastinum, and pneumothorax. Treatment involves visualizing anastomosis via bronchoscopy and CT scan to evaluate for possible surrounding air or infection.

Chronic lung allograft dysfunction (CLAD) remains a long-term complication with poor outcomes. CLAD has an obstructive-type disease pattern termed bronchiolitis obliterans syndrome (BOS), and a restrictive pattern termed restrictive allograft syndrome (RAS) or restrictive CLAD (rCLAD). Risk factors that have been identified for the two pathologies include CMV, gastroesophageal reflux disease (GERD), and episodes of acute rejection. Treatment involves the use of bronchodilators, steroids, treatment of GERD, and adjustments in immunosuppressive therapy.

3. Pancreatic Transplant

Pancreatic transplant is usually performed with either kidney or at times with small bowel transplant. Pancreatic transplantation is performed in patients who have diabetes mellitus without nephropathy. It should be of note that intraoperatively, pancreatitis and allograft edema are common because of reperfusion. Typically, diuretics are given to help alleviate edema and assist in microvascular perfusion. Therefore, it is essential to know whether osmotic diuresis helped with edema because if it did not, allograft function requires vigilant monitoring postoperatively.

Graft dysfunction is a complication of pancreatic transplants. The two most common causes of graft failure are rejection and thrombosis. The bleeding risk is lower in pancreatic transplant patients compared with other solid organs, and therefore intraoperatively, low-dose systemic heparin is administered to decrease thrombosis.

If a patient is experiencing ileus, fever, and abdominal pain, pancreatitis then pancreatic ischemia should be considered. Because amylase levels will be elevated postoperatively, the levels cannot be correlated with the severity of pancreatitis. However, if there is a rapid rise in amylase and lipase and requirements for exogenous insulin increase, graft ischemia or necrosis should be evaluated. Rejection ultimately needs the confirmation of a biopsy, and thrombosis is evaluated through the means of ultrasonography.

In patients who have pancreatic transplants with exocrine drainage through the bladder, rejection is suspected when urine amylase levels drop significantly. In males, the risk of urethritis is higher than in females. Bladder infection and metabolic acidosis can also occur. Metabolic acidosis is usually the result of losing bicarbonate in the urine. These patients also can become dehydrated early in the postoperative course.

4. Liver Transplant

Most liver transplant patients are monitored in the ICU. The first 72 hours are essential to frequently assessing hemodynamics using ultrasonography or through invasive monitoring. In the postoperative period, monitoring levels of hemoglobin are crucial for evaluating signs of bleeding. Patients may continue to be in a hyperdynamic circulatory state postoperatively given a history of portal hypertension. This finding can be challenging because it may mimic sepsis with increased cardiac output and decreased systemic vascular resistance. Cautions must be taken to not under resuscitate or over resuscitate the transplanted patient.

Graft function is monitored every 6 hours focusing on values of total bilirubin, lactate, glucose, international normalized ratio (INR), transaminases, and levels of potassium. Urine output and core body temperature are measured on an hourly basis. Decreased urine output, consistent rise in INR, lactate, transaminases, and inability to regulate normal body temperature are signs of inadequate allograft function. INR is usually elevated immediately postoperatively and should start to return to normal within 24 hours if the graft is properly functioning. Transaminases typically rise within the first 48 hours and begin to normalize a few days after. Bilirubin may take longer than other values before it starts to normalize but do be aware of drastic changes that may occur. A Doppler scan of the liver is performed within the first 24 hours to assess hepatic vein and artery flow.

Liver transplant patients should be extubated as soon as adequate graft function is evident. Furthermore, hemodynamic status and pain should be well controlled. Early nutrition is initiated to help decrease metabolic stress.

There are surgical and medical complications to a liver transplant.

a. Surgical Complications

Primary graft nonfunction is the failure of the liver graft, which is seen early in the postoperative period. Consistently elevated transaminases, INR and bilirubin, lactate, and worsening acidosis should raise concern for graft failure after acute infection, acute rejection, and hepatic vein or artery thrombosis have been ruled out. Although the complication of primary graft nonfunction is between 3% and 5%, the mortality is higher than 20%.

Vascular complications, such as thrombosis, occur early compared with stenosis or pseudoaneurysm, which occurs in later stages. Hepatic artery thrombosis is second to primary graft nonfunction as the most significant complication early in the postoperative period. Diagnosis can be challenging because some patients may not experience pain, whereas others may quickly have a drastic rise in transaminases to fulminant liver failure.

Immediate Doppler ultrasonography should be used, followed by potential arteriography or exploratory laparotomy at the discretion of the surgeon. Portal vein thrombosis occurs less frequently, clinically presenting as worsening ascites or variceal bleeding. Portal vein thrombosis is diagnosed by liver ultrasonography and if found early, thrombectomy and revision of anastomosis can be effective.

Bile leak is another major complication that occurs in about 15% of liver transplant patients. Patients may show signs of abdominal discomfort and fever. Suspicion should rise when abdominal pain is not resolving, and fever cannot be explained. Although ultrasonography may reveal a fluid collection, ultimately, cholangiography is definitive for diagnosis. Many bile leaks typically need abdominal exploratory laparotomy and washout.

In some cases, endoscopic stenting has shown success. Strictures and bilomas are later complications. Strictures usually present at the site of the anastomosis clinically revealing overt cholestasis or cholangitis. Based on the severity of the stricture, balloon dilation may be successful. In other cases, retransplantation may be required.

b. Medical Complications

i. Sepsis

Bacterial infections are more common than fungal and mostly arise from biliary leaks or deep surgical spaces within the abdomen. Aside from the surgical site as a potential source of infection, other possible sources of infections should be explored as well, such as indwelling catheters (Foley, central venous).

ii. Neurologic Complications

Clinical studies have reported rates of 8.3% to 47% for neurologic complications. The most common include encephalopathy, brain hemorrhage, and seizures. Patients who are encephalopathic before liver transplantation carry a higher risk of neurologic complications. Seizures are the second most common complication known to be a consequence of various factors stemming from metabolic disturbances, infection, stroke, or drug toxicity. Immunosuppression-related complications may reveal as headaches, confusion, myoclonus, delirium, and lowering the seizure threshold. Central pontine myelinolysis occurs in about 1% to 3.5% of patients after rapid correction of hyponatremia. Posterior leukoencephalopathy is a rare and severe manifestation activated by neuronal loss and reactive astrocytosis, usually the result of calcineurin inhibitors.

iii. Respiratory Complications

Transient pulmonary edema from sepsis or systemic inflammatory response syndrome (SIRS) may occur early in the postoperative period. Pneumonia is also common. Most pulmonary infiltrates are noncardiogenic pulmonary edema originating from abdominal sepsis. Pleural effusions are common on the right side postoperatively. As mentioned earlier, early extubation is vital, and if prolonged more than 7 to 10 days, tracheostomy should be considered. Patients with hepatopulmonary syndrome (HPS) have been reported to require a longer length of stay, primarily because of pulmonary vascular shunting causing hypoxemia. Pleural effusions are common after liver transplantation and tend not to cause respiratory compromise.

iv. Cardiovascular Complications

Transplanted liver patients classically present with hyperdynamic circulation resulting in increased cardiac index and low blood pressure. If a patient has a history of portopulmonary hypertension with high cardiac output, this tends to resolve post-transplant. In cases of low cardiac output, clinicians should evaluate volume status, bleeding, or stunned myocardium in the setting of SIRS or sepsis. Serial lactate measurement and echocardiography can assist in the hemodynamic management of these patients. In the acute setting postoperatively, colloid fluids, such as 5% albumin, are preferred for resuscitation. Albumin helps to maintain fluid balance, especially in liver transplant patients who tend to have hypoalbuminemia. Transplant surgeons should be made aware of patients' hemodynamics, especially when difficult to control with volume resuscitation.

v. Renal Complications

Renal complications vary widely in regard to post-liver transplant. Acute kidney failure ranges anywhere from 27% to 67%. At the discretion of the transplant surgeon, treatment typically includes renal replacement therapy and potential adjustments in immunosuppressive therapy that may be contributing to acute renal failure.

5. Kidney Transplant

Renal transplant patients typically do not need to go to the ICU postoperatively unless there is a concern for hemodynamic instability and respiratory complications. Immediate postoperatively, volume status needs to be monitored closely along with laboratory values (specifically including electrolytes, complete blood count), chest radiograph, and ECG. Renal ultrasonography is performed immediately after surgery.

Strict input and output are a crucial factor in managing patients postoperatively. It is imperative to keep patients heading toward a positive fluid balance considering the new kidney is in diuresis and there are insensible losses, which may average anywhere from 500–1000 mL/day. Patients should be kept toward a higher systolic blood pressure ≥ 150 mm Hg. If hypotension occurs, patients should be resuscitated with isotonic fluids.

Complications for a kidney transplant are detailed here.

a. Bleeding

If patients continue to be hypotensive with a decrease in hematocrit and experience abdominal pain, evaluation for intra-abdominal bleeding is warranted. If there are any drains or ureteral stents placed, the output should be monitored, and color change should be immediately reported to the surgeon. The output from drains is serosanguinous in the first few days. Therefore, if gross blood or any other change is noted, caution should be taken.

b. Graft Dysfunction

Graft thrombosis, arterial or venous, can occur in the first 72 hours. Venous thrombosis presents with hematuria and pain. Diagnosis is established by ultrasonography. Arterial thrombosis usually results in graft loss. Clinically there is an abrupt drop in urine output, with ultrasonography confirming the diagnosis. Renal artery stenosis can also occur but typically occurs a few months to 2 years later.

c. Urologic Complications

Urinary leaks occur early in the postoperative period. Symptoms present as tenderness over the graft site, fever, decreased urine output, and a rising creatinine. Analysis of drain output is sent for creatinine to confirm leakage. More substantial leaks require surgical repair.

6. Small Bowel Transplant

Small bowel transplant patients may be challenging because few specific markers are available to help guide management postoperatively. Clinicians need to be cognitive of specific laboratory findings and conduct regular physical examinations to determine whether the graft is functioning properly.

Ostomy output, lactate, hyperkalemia, and metabolic acidosis are valuable in assessing the graft. In these patients, volume depletion occurs because of inflammation and primarily a lack of absorption from the transplanted small bowel. Fluid resuscitation is challenging because, as with the pancreas where diuresis and fluid restriction may be considered, the transplanted small bowel also tends to be edematous. Therefore, in those instances, albumin 5% or albumin 25% is preferred for volume resuscitation.

Rejection is a complication of small bowel transplant. Rejection typically can occur within the first 30 days of transplantation. A biopsy is the gold standard for diagnosing rejection. In centers that perform small bowel transplants, endoscopies are conducted twice a week for the first month post-transplant. Patients who receive an intestinal transplant have significantly low albumin levels and are subject to malnutrition. If, for any reason, patients remain nothing by mouth for more than 3 days, it is preferred that nutrition is provided parenterally. Rejection is treated with adjustments in immunosuppression, corticosteroids, and plasmapheresis. Plasmapheresis is given postoperatively within the first 24 hours in patients who have elevated levels of donor-specific circulating antibodies.

B. Immunosuppressive Therapy

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Many common drugs affect immunosuppressive levels, so pharmacy consultation is suggested before introducing new drugs.

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Immunosuppression therapy is the mainstay treatment of transplanted patients. Transplant surgeons decide what kind of regimen their patients are prescribed. The primary intent in administering immunosuppression is to help prevent rejection of the transplanted organ. Typically, a corticosteroid, calcineurin inhibitors, and antiproliferative agents are used as immunosuppression agents. Moreover, monoclonal antibodies are used when a patient is resistant to steroids or to help decrease the effects of calcineurin inhibitors.

1. Corticosteroids

Methylprednisolone and prednisone are the steroids used in immunosuppression. Significant adverse effects to be aware of entail hyperglycemia, hypokalemia, metabolic alkalosis, myopathy, mood changes, hypertension, gastritis, encephalopathy, and increased the risk of infection.

2. Calcineurin Inhibitors

Interleukin-2 (IL-2) inhibitors, cyclosporine and tacrolimus, can be monitored via serum levels. However, be advised that serum levels may not correlate with the severity of the adverse effects depicted in patients. Both drugs are known to have nephrotoxicity and neurotoxicity as adverse effects with cyclosporine having less neurotoxicity than tacrolimus. Clinicians should remember to avoid low magnesium levels in patients taking calcineurin inhibitors because it may intensify neurotoxicity. Neurotoxic adverse effects are broad, ranging from headaches, tremors, seizures, delirium, cognitive impairment, dysarthria, posterior reversible encephalopathy syndrome to coma. Nephrotoxicity incidence and severity with cyclosporine increase with dose and duration of the medications and can occur even at traditional therapeutic drug serum levels. Patients who experience nephrotoxicity from cyclosporine and tacrolimus may be treated with sirolimus. Sirolimus blocks cytokine stimulation through mTOR inhibition without affecting calcineurin activity and prevents proliferation of T-lymphocytes and reduces antibody production. Sirolimus has been known to cause a higher incidence of hepatic artery thrombosis after liver transplantation, can delay wound healing, and may cause angioedema.

3. Antiproliferative Agents

Antimetabolite purine synthesis inhibitors include mycophenolate mofetil and azathioprine. Myelosuppression, electrolyte abnormalities, and gastrointestinal symptoms such as ileus, vomiting, diarrhea, and ulcers are common adverse effects. Azathioprine is used when patients are intolerant of the gastrointestinal adverse effects of mycophenolate mofetil.

4. Monoclonal Antibodies

Monoclonal antibodies consist of basiliximab and muromonab-CD3. Basiliximab blocks IL-2 receptors to inhibit activation of T-lymphocytes while muromonab-CD3 first activates T cells, which tends to exacerbate systemic inflammation.

5. Antimicrobials

Immunosuppressive therapy places patients at risk for infection and neoplasm. Aside from immunosuppressive therapy post-transplant, all patients are started on trimethoprim-sulfamethoxazole (TMP/SMX, Bactrim^{T}) for *Pneumocystis jirovecii* (PCP) prophylaxis. Depending on the history of the patient and previous exposure, patients may also be started on antivirals for prophylaxis against cytomegalovirus (CMV) and Epstein-Barr virus (EBV), hepatitis C virus (HCV), and hepatitis B virus (HBV). Patients who have received an organ from a seropositive donor remain at high risk, especially if the patient is seronegative. Furthermore, in the first month postoperatively, patients are at risk for nosocomial bacterial infections. Once the full effect of immunosuppressive therapy takes effect, which is typically between 1 to 6 months, opportunistic infections are more common. TMP/SMX substantially prevents infections such as PCP, *Listeria monocytogenes*, *Toxoplasma gondii*, and *Nocardia* species susceptible to sulfa. However, clinicians need to be cognizant of fungi, *Aspergillus*, *Cryptococcus*, *Trypanosoma cruzi*, and strongyloidiasis that may occur. Beyond 6 months, patients tend to have a lower risk of opportunistic infections because patients are at lower doses of immunosuppression.

C. Management of Adverse Effects of Therapy

In all transplanted patients, the most worrisome complication is rejection and failure of the graft. Adverse effects of immunosuppressive therapy and complications of surgery can affect the quality of life for these patients. This makes it imperative to identify complications sooner.

Ultimately, imaging, physical examination, and serum markers allow the clinician to recognize complications. Furthermore, immunosuppressive therapy can cause significant toxicity if combined with a medication that is either an inhibitor or inducer of liver cytochrome P-450 enzyme system. CYP3A4 is an isoenzyme involved in liver metabolism, and cyclosporine and tacrolimus are CYP3A4 substrates. Antifungals such as fluconazole, posaconazole, itraconazole, and voriconazole are potent CYP3A4 inhibitors.

If toxicity occurs, doses are adjusted at the discretion of the transplant team. Immunosuppressive therapy is rarely stopped because of higher risks of rejection. When acute rejection is confirmed by biopsy, immunosuppressive therapy may be adjusted for higher doses. Antilymphocyte antibodies have been shown to have a higher success rate in the treatment of acute rejection compared with steroids.

Key Points

Management of Special Populations

- Venous thromboembolism (VTE) is the third most common cardiovascular disorder. Approximately one-half are related to current or recent hospitalization.
- The mortality rate for acute PE exceeds 15% in the first 3 months after diagnosis.
- Early and late complications of bariatric surgery are uncommon and often difficult to diagnose.
- Anastomotic leak occurs most often during the first week of surgery. Leaks can present as respiratory failure.

- Nutritional deficiencies are common after bariatric surgery. Knowledge of the anatomic changes associated with each operation is essential to understanding possible complications.
- Diagnosis and management of organ-specific postoperative complications are essential in treating transplant patients.
- Immunosuppression therapy is the mainstay treatment of transplanted patients to prevent transplanted organ rejection.
- Corticosteroid, calcineurin inhibitors, and antiproliferative agents are used as immunosuppression agents. Monoclonal antibodies are used when a patient is resistant to steroids or to help decrease the effects of calcineurin inhibitors.

Suggested Readings

1. Antithrombotic Therapy for VTE Disease. CHEST Guideline and Expert Panel Report. *Chest*. 2016;149(2):315-352.
2. Prevention of VTE in Nonorthopedic Surgical Patients Antithrombotic Therapy and Prevention of Thrombosis, 9th ed: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines. *Chest*. 2012;141(2 Suppl):e227S–e277S.
3. Konstantinides SV, Torbicki A, Agnelli G, et al. 2014 ESC guidelines on the diagnosis and management of acute pulmonary emboli. *Eur Heart J*. 2014;35(43):3033-3080.
4. Diaz GC, Wagener G, Renz JF. Postoperative care/critical care of the transplant patient. *Anesthesiol Clin*. 2013;31(4):723-735.
5. Feltracco P, Barbieri S, Galligioni H, Michieletto E, Carollo C, Ori C. Intensive care management of liver transplanted patients. *World J Hepatol*. 2011;3(3):61-71.
6. Lau C, Patterson G, Palmer S. Critical care aspects of lung transplantation. *J Intensive Care Med*. 2004;19(2):83-104.

7. Ma IT, Madura JA. Gastrointestinal Complications after Bariatric Surgery. *Gastroenterol Hepatol (N Y)*. 2015;11(8):526-535.
8. Pagalilauan GL, Limaye AP. Infections in transplant patients. *Med Clin North Am*. 2013;97(4):581-600.
9. Pham P-TT, Pham P-CT, Danovitch GM. The acute care of the transplant recipient. In: McKay DB, Steinberg SM, eds. *Kidney Transplantation: A Guide to the Care of Kidney Transplant Recipients*. New York: Springer; 2010:207-235.

Suggested Websites

1. Metabolic and Bariatric Surgery Accreditation and Quality. https://www.facs.org/quality-programs/mbsaqip
2. American Society of Transplantation. https://www.myast.org/
3. American Society of Metabolic and Bariatric Surgery www.asmbs.org

Chapter 19

SURGICAL SOFT-TISSUE COMPLICATIONS AND URGENCIES

✓ Objectives

- Identify a healthy, healing wound.
- Recognize wound dehiscence and infection.
- Recognize and manage necrotizing soft-tissue infection (NSTI).
- Recognize and manage compartment syndrome.

Case Study 1

A 58-year-old man sustained trauma to his leg while working on his boat. He presented to the hospital with a painful open wound on the inferior portion of his leg. The patient was found to have a tibial fracture and he underwent closed fixation of the fracture. On postoperative day 2, he developed worsening pain. The skin along the surgical site became increasingly edematous. By postoperative day 3, erythema of the affected leg was increasing. He soon became persistently febrile, and the leg began to harden.

– Is this finding concerning?

– What distinguishes a normal wound from a complicated wound?

- What are the critical first steps in managing a wound complication?

Case Study 2

A 63-year-old man fell in the bathroom where he was found by a neighbor after almost 24 hours. At the hospital, he was found to have cervical spine fractures and minor head trauma. He was taken for cervical discectomy and fusion and was brought to the intensive care unit intubated, with a right internal jugular central venous catheter and a right radial arterial line. Over postoperative day zero, his right hand began to swell. His hand was elevated, and compresses were applied. By postoperative day 1, the edema of the hand had worsened and the arterial line was removed. The edema began to affect the distal portion of the forearm, and the affected area began to harden.

- What are the signs and symptoms of compartment syndrome?
- What are the critical first steps in managing compartment syndrome?

I. INTRODUCTION

Surgical wound infections are one of the most common adverse events in hospitalized surgical patients. Surgical site infections are classified as superficial incisional, deep incisional, and organ/space infections. These infections occur within 30 days of the surgery. Physical examination remains the most essential and reliable approach to diagnosis. Local examination findings of pain, swelling, erythema, purulent drainage, and wound dehiscence all suggest possible surgical site infections. However, not all surgical site infections may present this way.

II. POSTOPERATIVE WOUND CARE

For most operations, wound care is either straightforward or nonexistent because the skin is typically closed and covered with an occlusive dressing for the first 48 hours. However, this can vary significantly for emergency cases or those wounds associated with a significant amount of contamination. The location of the incision can frequently give information about what operation was performed and, therefore, what to expect postoperatively **(Figure 19-1)** (**Table 19-1**).

Figure 19-1. Common Incision Locations and Associated Operations

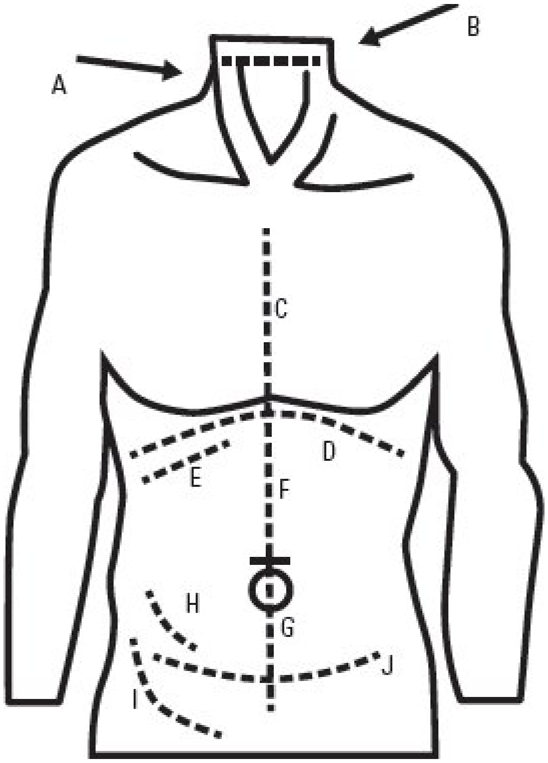

Table 19-1 Common Incision Locations and Associated Operations

Label	Incision	Possible Operations
A	Carotid	Carotid endarterectomy, neck dissection
B	Collar	Thyroid, parathyroid, tracheal resection
C	Sternotomy	Cardiac surgery
D	Chevron	Stomach, pancreas, liver transplant/resection
E	Subcostal	Liver/biliary procedures
F*	Upper midline	Gastric, pancreatic, small bowel
G*	Lower midline	Lower GI tract, genitourinary
H	McBurney's	Open appendectomy
I	Gibson	Renal transplant
J	Pfannenstiel	Obstetric/gynecologic procedures

* A complete midline incision (laparotomy) is occasionally performed if additional exposure is needed or the exact location of surgery is unknown preoperatively, such as in trauma.

A. Diagnosis

When caring for a postoperative patient, it is important to know what operation was performed, the length of the procedure, and the degree of contamination. The type of surgery can help predict the expected postoperative course and potential complications (eg, elevated liver enzymes are to be expected after liver resection, but could be problematic after a routine colectomy). More prolonged operations are associated with a higher likelihood of fluid or electrolyte disturbances, and operations with more contamination are associated with more frequent wound complications and increased risk of postoperative infections. The Centers for Disease Control and Prevention (CDC) has directed that each surgical procedure have a wound classification assigned (**Table 19-2**).

Table 19-2 CDC Wound Classifications

Label	Possible Operations
Class I/Clean	An uninfected operative wound in which no inflammation is encountered and the respiratory, alimentary, genital, or uninfected urinary tract is not entered. Also, clean wounds are primarily closed and, if necessary, drained with closed drainage. Operative incisional wounds that follow nonpenetrating (blunt) trauma should be included in this category if they meet the criteria.
Class II/Clean-contaminated	An operative wound in which the respiratory, alimentary, genital, or urinary tracts are entered under controlled conditions and without unusual contamination. Specifically, operations involving the biliary tract, appendix, vagina, and oropharynx are included in this category, provided no evidence of infection or major break in technique is encountered.
Class III/Contaminated	Open, fresh, accidental wounds. Operations with significant breaks in sterile technique (eg, open cardiac massage) or gross spillage from the gastrointestinal tract, and incisions in which acute, non-purulent inflammation is encountered are included in this category.
Class IV/Dirty-Infected	Old traumatic wounds with retained devitalized tissue and those that involve existing clinical infection or perforated viscera. This definition suggests that the organisms causing postoperative infection were present in the operative field before the operation.

Reproduced with permission Onyekwelu I, Yakkanti R, Protzer L, Pinkston CM, Tucker C, Seligson D. Surgical Wound Classification and Surgical Site Infections in the Orthopaedic Patient. *J Am Acad Orthop Surg Glob Res Rev*. 2017;1(3):e022. Copyright ○ 2017 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American Academy of Orthopaedic Surgeons.

As the wound classification increases, the risk of surgical site infections (SSI) or organ space infections increases as well. Although most incisions are covered with an occlusive dressing for 24–48 hours postoperatively, as the wound classification increases, it becomes more likely that the wound will not be closed at the time of operation.

The healing of a surgical wound takes place by one of three mechanisms. For most operations, the tissues of a clean incision are reapproximated with sutures, which is referred to as healing by primary intention. If there is significant contamination of the wound, only the deep layers will be closed, and the superficial layers will be allowed to heal by the formation of granulation tissue and wound contraction. This is referred to as healing by secondary intention. Although it takes longer, the risk of wound infection is significantly lowered. A combination of these two techniques involves placing sutures at the time of the operation, leaving the wound open for several days, and then closing the wound by tying the sutures. This is referred to as delayed primary closure or healing by tertiary intention.

B. Management

1. Phases of Wound Healing

The healing of any wound, surgical incisions included, follows a predictable pattern of phases that can be characterized by the types of cells present and the predominant activity of those cells. Although these phases overlap in their duration, they follow a consistent linear pattern, and derangement in any stage will prevent the re-establishment of tissue integrity. These phases are as follows:

- Inflammatory Phase
- Proliferative Phase
- Maturation Phase

The healing process begins with the initial injury. As tissues and blood vessels are disrupted, the extracellular matrix and collagen are exposed, allowing for platelet aggregation. Platelets then release a variety of active substances that promote the formation of a fibrin clot. After the wound becomes hemostatic, local tissue factors and platelets promote vasodilation and increase capillary permeability. This allows for the influx of inflammatory cells (predominantly neutrophils) and fluid, which causes the wound to become erythematous, edematous, and warm. The neutrophils mainly facilitate the phagocytosis of bacteria and removal of dead tissue, and, in experimental models, do not seem to be critical to wound healing. After 2–3 days, macrophages will become the predominant inflammatory cell and help to facilitate matrix deposition, angiogenesis, and tissue remodeling by the release of cytokines and tissue growth factors. Macrophages may be the most important cell involved with healing because of the aforementioned effects, and they will remain until the wound has completely healed.

The proliferative phase of wound healing is characterized by the influx of endothelial cells and fibroblasts, which outnumber inflammatory cells by approximately postinjury day 4. By day 5–7, there is no longer a large population of inflammatory cells remaining in the wound. Type III collagen is being replaced by type I collagen, and for the next 2–3 weeks, angiogenesis, the formation of granulation tissue and wound contraction, will take place.

The final phase of wound healing (maturation/remodeling) begins around 3–4 weeks and will persist for months. At this point, collagen cross-linking will take place and, even though collagen is continuing to be synthesized, it is being broken down at almost the same rate that it is being created. Vascularity will also decrease during this phase until an acellular and avascular scar is formed. See **Table 19-3** for factors that can impair wound healing.

Table 19-3 Factors That Can Impair Normal Wound Healing

- Decreased wound oxygen (hypoxia, anemia, hypoperfusion)
- Advanced age
- Steroids
- Chemotherapeutics
- Disorders of metabolism (eg, diabetes, obesity)
- Poor nutrition
- Micronutrient deficiencies (eg, Vitamin A, Vitamin C, Zinc)
- Infection

2. Wound Dressings

The most common postoperative wound dressing is an occlusive dressing that prevents a clean wound from being exposed to bacteria until epithelization takes place at about 24–48 hours. In general, these dressings should be left in place unless an early postoperative wound infection is suspected (erythema, excess drainage, fevers, etc.). Surgeries associated with large or chronic wounds can be managed with a variety of different dressing types. The ideal dressing maintains a moist environment, removes excess exudate, does not cause further damage to the wound with removal, protects the wound from further trauma, is impermeable to bacteria, requires infrequent changes, conforms to the wound easily, minimizes pain, and is cost-effective. A list of common dressings and their potential advantages/disadvantages are listed in **Table 19-4**.

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Dressings are frequently forgotten in critically ill patients and left in place for too long. These wounds should be periodically inspected, especially in the setting of unexplained fevers. In general, simple dressings that are saturated, bloody, or covering a wound with suspicious drainage can safely be removed, the wound inspected, and replaced with a clean dressing.

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Table 19-4 Common Wound Dressings

Dressing Type	Advantages	Disadvantages	Ex. Indications	Surveillance
Gauzes*	Inexpensive, accessible	Desiccation, ineffective barrier	Deep wound packing	12 to 24 hours
Semi-occlusive films	Retains moisture, protects from contamination	Non-absorptive traps in fluid/exudate	Minimal exudate, or as a secondary dressing	Up to 7 days if dry
Hydrogels	Retains moisture, pain relief, easy to remove	Potential for overhydration	Dry/painful wounds	Change every 1–3 days
Hydrocolloids	Absorbent, occlusive, infrequent dressing changes	Obscures wound, can increase wound odor	Light to moderate exudate	Up to 7 days
Alginates/ Hydrofibers	Very absorbent, hemostatic	Can leave debris in wound	Moderate to heavy exudate	Leave in place until too wet
Foams	Absorbent, occlusive	Obscures wound, can increase wound odor	Light to moderate exudate	Change every 3 days
Topic Skin Adhesive	Occlusive	Limited indications	Clean, fresh wounds only	7–10 days
Negative pressure wound therapy (NPWT), or vacuum-assisted closure (VAC)	Manages exudate, increases granulation tissue formation, infrequent changes	Painful to change, cannot be placed on exposed organs or vascular structures, actively bleeding or infected wounds	Chronic or large wounds, wounds with lots of exudate	3–5 days
Antimicrobial (eg, iodine or silver-impregnated)	Potentially helps reduce bacterial colonization or infection	Potential adverse reaction	Wounds with high infection risk (eg, burns)	Variable

* Gauzes are typically soaked in saline to prevent wound desiccation. However, they can also be soaked in antimicrobial solutions such as povidone-iodine or Dakin's solution.
Data taken from Fonder MA, et al. Treating the chronic wound: A practical approach to the care of nonhealing wounds and wound care dressings. *J Am Acad Dermatol* 2008;58(2):185-206.

3. Surgical Drains

The management and purpose of surgical drains and tubes are frequently overlooked by treating physicians who are not part of the surgical team that placed them. Part of any surgical sign out should include a description of any drains or tubes including the location of the drain (subcutaneous vs. deep organ space), the purpose of the drain (remove excess fluid vs. monitor for changes in output), the proper care of the drain (active vs. passive), and things that would be concerning (increased output, decreased output, change in the appearance of output, etc.). Also, instructions should be given for what to do if the drain comes out: is it an emergency, or can it be safely left out? This should be clarified even for common drains like a nasogastric tube or indwelling bladder catheters. For instance, there may be a risk of injury by replacing a nasogastric tube in a patient with a fresh esophageal anastomosis, and a indwelling catheter may be protecting a bladder repair or ureteral anastomosis in the case of renal transplant.

The following is a description of different types of drains and their typical purpose (**Figure 19-20**):

a**. Jackson-Pratt (JP):** These are radiopaque silicone or PVC tube drains that can be either round, flat, or multi-channeled. They are commonly attached to a bulb suction device that provides active suction. Their location typically dictates what function they are supposed to perform. Placed in the subcutaneous tissues of the neck, breast, extremities, or near surgical incisions, they are primarily for drainage of excess thin exudates that could potentially create a seroma. Placed intra-abdominally or intra-thoracically, they can serve to drain exudate or monitor for changes in output (eg, sudden production of bile or succus could indicate an anastomotic leak).

b. **Blake:** These are radiopaque silicone drains with four channels surrounding a solid core. They are typically attached to a bulb suction device and are placed in similar locations and for the same purposes as JP drains. There usually is a manufacture mark that indicates the most distal extent of draining channels and should remain at or below the level of the skin.

c**. Davol/Hemovac:** These drains are similar in structure to JP and Blake drains, although they are typically larger and attached to an evacuator that is spring-loaded and can hold a larger volume (~400 mL). They are commonly used in neurosurgical or orthopedic procedures for the control of exudate and bleeding.

d**. Sump drain:** Sump drains typically have three lumens that allow for the application of suction, installation of fluids, and an air vent. They generally are allowed to drain by gravity to a collection bag and are placed intra-abdominally to facilitate the removal of large volumes of thicker exudates.

e. **Malecot:** This is a latex drain tipped with a splayed, mushroom-shaped tip that drains by gravity to a collection bag. It is typically placed in the urinary system as a nephrostomy tube or enterally. Enterally, its function is for diversion of intestinal contents or to allow access for feeding.

f. **Abdominal wound VAC:** This is a temporary abdominal closure device that provides an egress for abdominal exudates and as an occlusive barrier to prevent contamination of an open abdominal wound. Careful attention should be paid to output because a significant amount of fluid can be lost through an open abdominal incision.

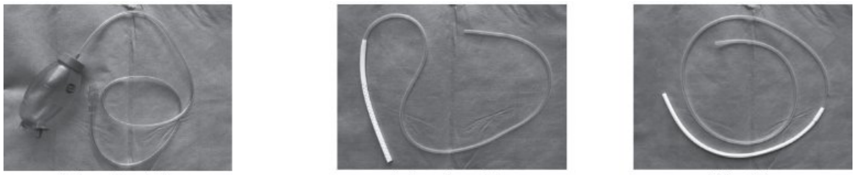
g. **T-tube:** This tube, traditionally placed into the bile duct, is also used to create controlled fistulae after duodenal or esophageal perforations. They serve to either protect a biliary anastomosis or provide egress for obstruction (eg, choledocholithiasis or malignancy). They can either be allowed to drain by gravity or attached to a suction device (eg, bulb suction).

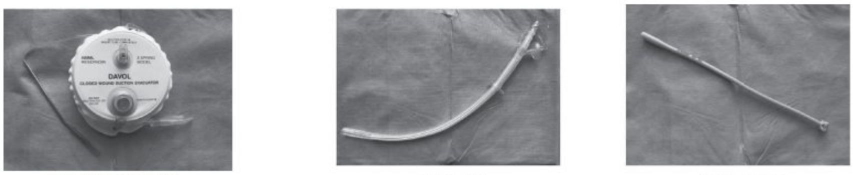
h. **Cholecystostomy tube:** This drain is placed directly into the gallbladder to allow for the egress of bile when cholecystectomy cannot be immediately performed. It can be placed surgically or percutaneously, often transversing liver parenchyma.

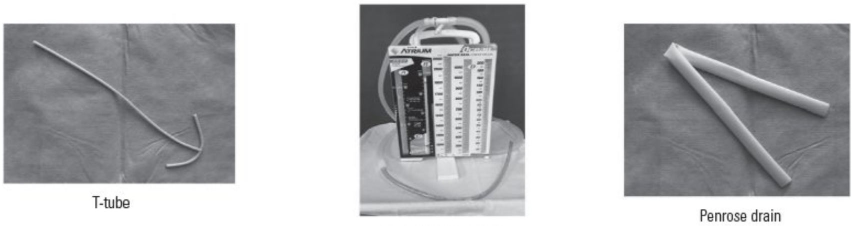
i. **Tube thoracostomy:** These drains come in a variety of sizes from a pigtail drain (8–14F) used for pneumothorax to a large 36F silicone tube placed for the evacuation of a hemothorax associated with trauma. They are connected to a three-chamber drainage device that allows for the collection of output (collection chamber), prevents the reflux of air into the pleura (water-seal chamber), and prevents the application of excessive suction (suction chamber) that could injure the lung. While active bubbling in the suction chamber simply indicates that suction is being applied, bubbling in the water-seal chamber indicates air is being removed from the pleural space. Active suction assists with the evacuation of air, but typically does little for the egress of fluid because the amount of suction applied is usually low (~20 cm H_2O). Fluid often needs to drain by gravity. After pneumonectomy, chest tubes are not typically placed to suction because it can cause acute mediastinal shift.

j. **Penrose:** These drains are flat, flexible open system drains that provide egress of fluids and prevent premature closure intentional sinus tract. Replaced mainly by closed drain systems mentioned previously, Penrose drains are still used in selected situations and resource-limited environments. Penrose drains need to be secured to prevent both egress out of the wound but also inadvertent advancement and loss into the wound.

Figure 19-2. Types of Surgical Drains


Jackson-Pratt (JP) drain with bulb
Jackson-Pratt (JP) drain without bulb
Blake drain


Davol/Hemovac drain
Sump drain
Malecot drain


T-tube
Tube Thoracostomy
Penrose drain

III. WOUND DEHISCENCE

Wound dehiscence is a surgical complication that refers to the partial or complete disruption of one or multiple layers of surgical wound closure. It ranges in severity from the partial separation of the skin to complete fascial disruption and evisceration of abdominal viscera. While this is an infrequent problem, especially in young, healthy patients, the risk increases with age or systemic illness.

A. Diagnosis

One of the most important aspects of diagnosing wound complications is identifying those patients that are at increased risk. Systemic factors that can potentially lead to dehiscence include those that contribute to delayed wound healing (eg, diabetes mellitus, sepsis, immunosuppression, malignancy, nutritional deficiencies) and those that increase intra-abdominal pressure (eg, obesity, ileus, coughing). Ascites can also contribute by both increasing intra-abdominal pressure and by the constant leakage of fluid through the incision, preventing reapproximation of the wound, and providing a route for infection to develop. Technical factors associated with the closure (ie, suture selection and placement of sutures) can also increase the risk of dehiscence. However, this information cannot typically be assessed once the wound has been closed. In reality, it is usually a combination of factors that contribute to wound disruption, and special attention should be paid in those patients at higher risk. Interventions aimed at reducing these risk factors (NG tube for ileus, abdominal binder for obesity or coughing, preoperative nutritional optimization, etc.) are more desirable than dealing with the complication.

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>
> *While new serosanguinous drainage from a wound could be nothing more than a subcutaneous fluid collection, it could also herald fascial dehiscence, which could progress to evisceration. Prompt surgical consultation is warranted.*
>
> !

Although it can occur at any time, dehiscence usually takes place approximately 7 days after the initial operation when the tensile strength of the wound is at its lowest. The earliest sign of dehiscence is typically the egress of serosanguinous fluid or discharge from a previously dry incision. However, it can also present as the sensation of “something popping” while coughing or sudden evisceration. In the case of thoracic incisions, this can also manifest as air leaking from the wound or paradoxical chest wall movement. However, the dehiscence of thoracic incisions is less common because the surrounding ribs typically support the incisions, and there is less pressure from underlying viscera. If the skin of the wound has separated, the integrity of the fascial closure can be tested by gently probing the wound with a cotton-tip applicator.

B. Management

At a basic level, the management of dehiscence is reclosing the wound, especially if it is in the early postoperative period. The degree of dehiscence will also dictate the treatment and the urgency of intervention. If the underlying fascia is intact and the dehiscence is limited to the skin, these wounds can usually be treated with packing alone. However, if all of the wound layers have been compromised, it typically requires urgent reoperation.

Abdominal laparotomy incisions with fascial dehiscence should be stabilized with an abdominal binder and returned to bed to prevent progression to evisceration. At this point, the patient should be returned to the operating room, and the surgeon will typically open the wound and re-do the fascial closure. Frequently, the skin is also left open to prevent wound infection, and the wound either packed with saline-soaked gauze or a negative pressure wound therapy device is applied. In the event of complete evisceration, the patient should be returned to bed, the viscera covered with a saline moistened sterile non-adherent dressing and the patient prepared for emergent return to the operating room. No attempt should be made to return the bowel to the abdominal cavity outside of the operating room. If there is only partial dehiscence and there is significant contamination of the wound from infection or the patient is a poor surgical candidate, it may be prudent to avoid reoperation. In this case, the skin closure should be maintained, the incisions should be supported with a binder or corset, and a resulting incisional hernia is to be expected. However, even small defects can serve as a site of bowel herniation and incarceration that can potentially complicate this approach.

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If fascial dehiscence results in the evisceration of abdominal contents, the most important thing to do preoperatively is return the patient to bed and keep the viscera moist with sterile towels.

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Sternal wounds require special attention because they are almost uniformly caused by infection and require urgent debridement and reapproximation to prevent sternal nonunion or more serious mediastinal infection. With the exception of significant sternal osteomyelitis, most sternal wounds can be effectively reclosed. However, they will occasionally require mediastinal irrigation or closure with a pectoralis major flap.

IV. NECROTIZING SOFT-TISSUE INFECTON (NSTI)

Necrotizing surgical site infections differ from milder infections in that they involve deep fascial and muscle compartments. Necrotizing soft-tissue infection is a destructive infection that tracks along superficial fascia. Presentation is often one of cellulitis; affected tissue will have a “wooden-hard” induration, and severe pain that may seem disproportionate to physical examination. Skin may have bullous lesions, necrosis, or crepitus, suggestive of gas within the tissue. Patients often will have fever and as the infection progresses may develop hemodynamic instability that can result in organ failure and ultimately death if not treated promptly and correctly. While surgical site infections rarely occur in the first 48 hours after surgery, when surgical site infections occur within the first 48 hours, they are often due to *Streptococcus pyogenes* or *Clostridioides* species. Common organisms are *Streptococcus pyogenes*, *Staphylococcus aureus*, *Vibrio vulnificus*, or *Aeromonas hydrophila* but surgical site infections can also be polymicrobial.

A. Background

Skin and soft-tissue infections (SSTIs) include infections of the superficial or deeper structures of the skin and surrounding tissues. They range from non-necrotizing SSTIs, which include superficial infections (impetigo, erysipelas, cellulitis) and purulent types (simple and complex abscesses, furuncles, and carbuncles). The severity can range from mild to severe depending on the extent of progression and presence of systemic response. Necrotizing SSTIs (NSTIs) may involve the dermis in cases of necrotizing cellulitis, superficial and deeper fascia as well as subcutaneous fat in cases of necrotizing fasciitis, and the muscle layer in cases of myonecrosis. Fournier's gangrene is a NSTI confined to the genital area, including the perineum, scrotum, penis, or vulva. Severe NSTIs typically have signs and symptoms of sepsis or septic shock. Bullae, skin sloughing and necrosis are concerning signs of deeper infection. Without appropriate control of the source, NSTIs can quickly progress and are associated with increased morbidity and mortality. (**Table 19-5**)

Table 19-5 Skin and Soft-Tissue Structures and Associated Syndromes

Anatomy	Syndrome
Skin Epidermis Dermis	• Erysipelas • Impetigo • Folliculitis • Ecthyma • Furunculosis • Carbunculosis • Cellulitis
Subcutaneous Tissue Subcutaneous fat Nerves Arteries Veins Deep fascia	• Cellulitis • Necrotizing fasciitis
Muscle	• Myonecrosis (clostridial and non-clostridial)

B. Epidemiology and Risk Factors

The overall incidence of cellulitis is estimated to be 24.8/1000 patient-years. Conversely, the incidence of necrotizing fasciitis is less common with an incidence of 0.04/1000 patient-years, although this does not include other forms of NSTIs and is limited to *Streptococcus pyogenes*. The overall rates of NSTIs have reported to be increasing, which are purported to be the result of increasingly resistant organisms. According to Surgical Infection Society clinical practice guidelines, the mortality remains high for these patients (mean 23.5%, range 7% to 70%). However, a more recent evaluation reported an average mortality rate of 14% (range 9% to 22%), which may reflect improved mortality with modern care focusing on early initial debridement, repeated debridement to obtain adequate source control, early and appropriate antimicrobials, and supportive care. Based on several evaluations, one major factor associated with increased mortality rates is the delay to surgical debridement. Other clinical factors associated with increased mortality includes age 50 years and greater, increased involvement of body surface area, lactic acidosis, hypotension, organ dysfunction at admission, immunocompromised state, and a white blood cell count greater than 30,000/mm^3. Although true risk factors are not well known, reported risk factors for NSTI, methicillin-resistant *Staphylococcus aureus* (MRSA), and community-acquired MRSA (CA-MRSA) are included in **Table 19-6**.

Table 19-6 Risk Factors Associated with NSTI, MRSA, and CA-MRSA

NSTI	MRSA	CA-MRSA
Increasing age	Increasing age	Contact sports
Peripheral vascular disease	Residing in long-term acute care or skilled nursing facility	Injection drug abuse
Alcohol abuse	Prior MRSA infection or colonization	Men who have sex with men
Injection drug abuse	Prior hospital admission or antimicrobial usage	Military personnel
Co-morbidities: Diabetes mellitus, immune compromised state	Skin lesions or pressure ulcers	Inmates of correctional facilities
Obesity	Comorbidities: Diabetes mellitus, heart failure, lung disease, chronic kidney disease	Post-influenza-like illness and/or severe pneumonia
Idiopathic		Concurrent SSTI

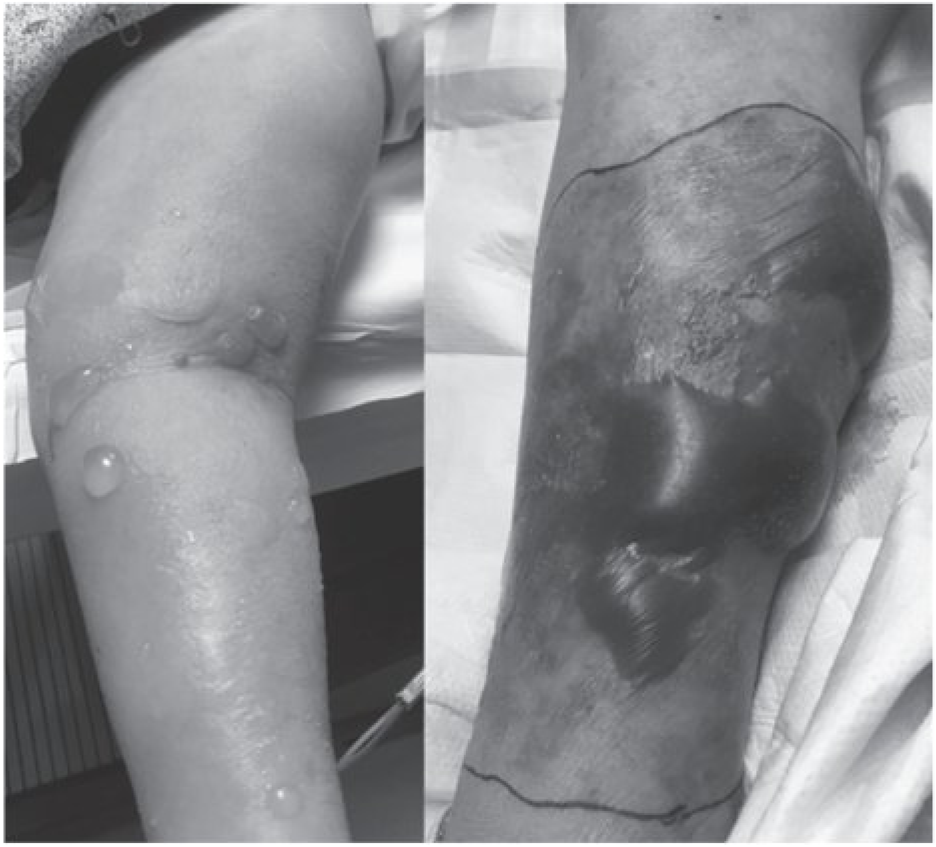
Abreviations: NSTI, necrotizing soft-tissue infection; MRSA, methicillin-resistant *Staphylococcus aureus*; CA-MRSA, community-acquired methicillin-resistant *Staphylococcus aureus*

C. Diagnosis

1. Clinical Presentation and Physical Examination

Early diagnosis is paramount in minimizing morbidity and mortality for patients with NSTI. Clinical presentation represents a major challenge for the diagnosis because of nonspecific complaints, such as nonspecific pain, gastrointestinal symptoms (ie, nausea, vomiting, diarrhea), and influenza-like symptoms. In addition, physical examination findings may only consist of mild local erythema and may be difficult to distinguish from cellulitis. Other clinical manifestations for necrotizing fasciitis include soft-tissue edema, erythema, severe pain, tenderness, fever, and skin bullae and necrosis. Bullae and necrosis are often late signs (**Figure 19-3**). Patients may, however, present with the absence of fever by self-administration of antipyretics, absence of cutaneous manifestations, attributing pain to an injury or procedures, or attribute systemic manifestations to other causes, such as nausea, vomiting, and diarrhea. Therefore, recognition and diagnosis may be challenging. In an evaluation of missed diagnosis of NSTI by primary care or emergency room physicians, patients were misdiagnosed as having musculoskeletal pain (40%), influenza (20%), gastroenteritis (13%), hemorrhoids (6%), gout (6%), first-degree burn (6%), and varicella (6%).

Figure 19-3. Examples of Necrotizing Soft-Tissue Infection



Images courtesy of Mary Jane Reed, MD

2. Laboratory and Imaging

According to surgical clinical guidelines, some clinical features may be strongly suggestive of a NSTI. These may include pain disproportionate to physical examination findings, tense edema, bullae, skin ecchymosis or necrosis, cutaneous anesthesia, progression despite antimicrobial therapy, and signs of systemic toxicity. Systemic signs may range from leukocytosis greater than 14×10^9/L, serum sodium level less than 135 mEq/L, blood urea nitrogen level greater than 15 mg/dL, to septic shock requiring vasopressors. A rapidly progressive soft-tissue infection should strongly be considered to be a NSTI. Scoring systems have been evaluated and suggested to aid in the diagnosis of NSTI. The most extensively studied is the Laboratory Risk Indicator for Necrotizing Fasciitis (LRINEC) score, which includes C-reactive protein levels, white blood cell count, hemoglobin, serum sodium, serum creatinine, and serum glucose. A score of 6 or greater was found to have a sensitivity, specificity, positive predictive value, and negative predictive value of 90%, 95%, 92%, and 95%, respectively. While the original study was promising, more recent studies have not replicated these findings and a score of less than 6 cannot rule out the diagnosis of NSTI (**Table 19-7**).

Table 19-7 Laboratory Risk Indicator for Necrotizing Fasciitis (LRINEC) Score

Criteria	Value	Points
CRP (mg/dL)	<15	0
	≥15	+4
WBC (×10,000/μL)	<15	0
	15–25	+1
	>25	+2
Hemoglobin (g/dL)	>13.5	0
	11–13.5	+1
	<11	+2
Sodium (mEq/L)	≥135	0
	<135	+2
Creatinine (mg/dL)	≤1.6	0
	>1.6	+2
Glucose (mg/dL)	≤180	0
	>180	+1

Reproduced from Wong CH, Khin LW, Heng KS, et al. The LRINEC (Laboratory Risk Indicator for Necrotizing Fasciitis) score: A tool for distinguishing necrotizing fasciitis from other soft tissue infections. *Crit Care Med*. 2004;32(7):1535-41. Copyright ○ 2004 by the Society of Critical Care Medicine and Lippincott Williams & Wilkins.

Imaging may aid in the diagnosis and should be considered when the diagnosis is undetermined by clinical history or physical examination findings. Plain radiographs may only be helpful if gas is present, which only occurs in approximately one-third of patients, thus providing low sensitivity. Although there is no gold standard, either computed tomography (CT) or magnetic resonance imaging (MRI) may be useful in the detection of soft-tissue gas; however, an MRI may be difficult to obtain under an emergent situation in addition to the increased cost and limited availability. CT imaging is more sensitive for the presence of soft-tissue gas and inflammatory changes (up to 80%), but may not be specific for NSTI. Alternatively, ultrasound may aid in the diagnosis for those unstable patients to differentiate cellulitis from necrotizing fasciitis. Furthermore, imaging may be useful to identify other potential diagnoses, such as abscesses. Although diagnostic studies have possible utility for the diagnosis of NSTI, direct examination in the surgical setting may be required to make a definitive diagnosis, thus emphasizing the need for early surgical consultation and a very low threshold for surgical exploration. Delays in diagnosis and treatment of these infections may be associated with significant mortality and morbidities, further elevating the importance of early diagnosis and surgical management.

3. Microbiology

Type I infections are the most common type of NSTI, accounting for at least 85% to 90%. These infections generally have a mixture of aerobic and anaerobic organisms, including gram-positive, gram-negative, and anaerobic pathogens that typically arise from a chronic, indolent source and spread along a fascial plane. A type II infection is the second most common type, and typically include gram-positive aerobic pathogens, including *Streptococcus* species and CA-MRSA. These pathogens are known to be virulent related to their toxin production. A type III infection is a monomicrobial infection caused by other gram-positive or gram-negative species, such as *Clostridioides* or *Bacillus* species. Other types of monomicrobial NSTIs include water-borne pathogens, such as *Vibrio vulnificus* and *Aeromonas hydrophila*. Patients with liver disease, including alcoholic cirrhosis, chronic hepatitis, and hemochromatosis, may be predisposed or higher risk for *Vibrio* infections. Another type of monomicrobial infection that typically involves the rhino-orbital-cerebral passages or paranasal sinuses should be strongly considered for *Mucor* or *Rhizopus* infections. Patients with increased risk include those with immunosuppression, diabetes mellitus, iron overload, and recent treatment with deferoxamine. Other types of fungal infections are not typical for NSTI, but may still occur.

D. Management

1. Early Surgical Debridement

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Clinical deterioration in a patient with NSTI should prompt immediate reevaluation of wounds for need of further emergent surgical debridement.

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An early surgical consultation is paramount for the management of patients with NSTI. Immediate surgical debridement is considered the cornerstone of therapy while adjunctive therapies are also necessary, including appropriate empiric antimicrobials and supportive care. A delay in surgical debridement and inadequate debridement is associated with worse outcomes, including increased risk of mortality. Subsequent debridement is likely necessary with the second exploration within a 24- to 48-hour period. In addition, these patients receive an average of four total debridements to achieve source control. Amputations may be necessary when a limb is not viable or not expected to be functional. Diverting colostomies may be needed for Fournier's gangrene to prevent soiling of the perineum. Once source control is achieved and no further debridements are necessary, skin grafts and/or flaps or use of wound vacuum-assisted closure (VAC) may be used.

2. Initial Resuscitation

Initial resuscitation is critical for these patients, especially for those with severe systemic symptoms and shock. Fluid resuscitation is needed to replace intravascular volume, initial management of hypotension, and optimizing blood volume to maintain tissue perfusion. Crystalloids, including normal saline or balanced crystalloids, such as Plasmalyte or lactated Ringer solution, are typically considered first-line for initial fluid resuscitation. Packed red blood cell transfusions may be needed for patients with significant blood loss during the surgical procedure or anemia from hemolysis caused by toxin production. Other blood products, such as platelets and fresh frozen plasma, are not routinely needed and should be reserved for those with significant thrombocytopenia and coagulopathy, respectively. For patients presenting in septic shock, after adequate fluid resuscitation, vasopressor therapies may be needed to maintain adequate mean arterial pressure greater than 65 with norepinephrine and vasopressin or epinephrine considered first- and second-line therapies, respectively. Multiorgan failure is common in patients with NSTI and additional therapies may be necessary.

3. Antimicrobial Therapy

Empiric antimicrobial therapy should be broad to include the likely pathogens involved and should be initiated promptly. Clinical guidelines for patients presenting with sepsis and septic shock suggest initiation of antimicrobials within 1 hour of presentation. The likely pathogens may differ based on the clinical setting, pathophysiology, and previous exposure to antibiotics. In addition to surgical debridement, empiric antimicrobials should include a broad-spectrum beta-lactam agent, including piperacillin/tazobactam, carbapenem, or a third- or fourth-generation cephalosporin/metronidazole combination for coverage directed toward gram-negative, gram-positive, and anaerobic pathogens. In addition, coverage toward MRSA should be included with vancomycin typically considered a first-line treatment. Empiric clindamycin should be considered for NSTI to decrease toxin production associated with invasive group A streptococcal infections. Those patients suspected to have a NSTI involving the rhino-orbital-cerebral areas and paranasal sinuses should receive empiric coverage toward *Mucor* and *Rhizopus* with lipid formulation amphotericin B or posaconazole. Definitive therapy should target the specific pathogen grown from microbiologic data and de-escalated to the most narrowed spectrum agent. Specific recommendations are summarized in **Table 19-8**. Duration of therapy ultimately depends on the ability to obtain source control with expert recommendations suggesting within 72 hours with clinical improvement.

Table 19-8 Summary of NSTI Types

Type	Type I: Polymicrobial	Type II: Gram-Positive Monomicrobial	Type III: Other Monomicrobial	Other: Monomicrobial	Other: Fungal
Patient-Related Factors	Multiple co-morbidities, failure of host immune response, males	None specific	Immunosuppression or malignancy	Underlying liver disease, including alcoholic cirrhosis, chronic hepatitis, and hemochromatosis *(Vibrio)*	Immuno-suppression, diabetes mellitus, iron overload, treatment with desferoxamine
Common Anatomic Location	Perineum or genital areas; submandibular space, neck and mediastinum (Ludwig's angina)	Site of injury or trauma	Site of injury or trauma; surgical site	None specific	Rhino-orbital-cerebral; paranasal sinuses
Precipitating Factors	Minor injuries; genitourinary, colorectal, or dermatologic sources (ie, perirectal abscess, chronic urethral strictures, and Bartholin gland abscesses)	Minor injuries or local trauma; NSAID therapy; Abdominal surgery; decubitus ulcer; intravenous drug use; spread from genitourinary tract	Deep penetrating wound; crush injury; intestinal surgery; black tar heroin injection (skin popping); obstetrical complications (retained placenta, prolonged rupture of membranes and spontaneous aborption)	Water-borne, handling of seafood	None specific
Common Pathogen(s)	Gram-positive: staphylococci, streptococci, enterococci Gram-negative: *Pseudomonas aeruginosa, Escherichia coli, Enterobacter* sp., *Klebsiella* sp., *Serratia* sp., *Proteus mirabilis* Anaerobes: *Bacteroides* sp. Ludwig's: peptostreptococcal sp., fusobacteria	Gram-positive: CA-MRSA, MRSA, *Streptococcus* species, including β-hemolytic or group A (*S. pyogenes*)	*Clostridioides* species	*Vibrio vulnificus, Aeromonas hydrophila*	*Rhizopus, Mucor*

Antimicrobial Coverage[1]	Empiric therapy: Broad-spectrum beta-lactam[2,11] PLUS vancomycin[3,11] PLUS clindamycin[4] Definitive therapy: based on susceptibility data	Definitive therapy: CA-MRSA, MRSA: vancomycin or based on susceptibility data; *S. pyogenes*: penicillin[5,11] PLUS clindamycin	Definitive therapy: penicillin PLUS clindamycin	Definitive therapy: *Vibrio*: doxycycline[6] PLUS ceftriaxone[7]; *Aeromonas*: doxycycline PLUS ciprofloxacin[8,11]	Empiric and definitive therapy: lipid formulation amphotericin B[9] or posaconazole[10]

Footnote: 1) Duration of coverage is at least 72 hours after a source control procedure and consider infectious disease consultation. 2) Broad-spectrum beta-lactam options, including pipercillin/tazobactam 3.375–4.5 g IV every 6 hours, imipenen-cilastatin 1 g IV every 6–8 hours, meropenem 1–2 g IV every 8 hours, ertapenem 1 g IV every 24 hours, and ceftazidime 2 g IV every 8 hours or cefepime 1–2 g IV every 8 hours given with metronidazole 500 mg IV every 8 hours. 3) 30 mg/kg/day given in 2 divided doses. 4) 600–900 mg IV every 8 hours. 5) 2–4 million units IV every 4–6 hours. 6) 100 mg IV every 12 hours. 7) 1–2 g IV every 24 hours. 8) 400 mg IV every 12 hours. 9) 3–5 mg/kg/day depending on formulation. 10) 400 mg PO twice daily with meals. 11) Renal dose adjustments necessary.
Abbreviations: CA-MRSA, Community-acquired methicillin-resistant *Staphylococcus aureus;* SP., species; NSAID, nonsteroidal anti-inflammatory drug; immunosuppression: includes hematologic malignancies, organ transplant, AIDS, chronic steroid use; AIDS, acquired immunodeficiency syndrome.
References: Ustin JS, Malangoni MA. Necrotizing soft-tissue infections. *Crit Care Med* 2011;39(9):2156-62.; Stevens DL, Bisno AL, Chambers HF, et al. Practice guidelines for the diagnosis and management of skin and soft tissue infections: 2014 Update by the Infectious Disease Society of America. *Clin Infect Dis* 2014;59(2):e10-52.

4. Adjunctive Therapies

Patients with NSTI may have electrolyte and acid-base disturbances that require close monitoring. The most common electrolyte disturbances include mild hyponatremia and hypocalcemia. The hyponatremia encountered in NSTI is typically a hypotonic hypovolemic type and thus, responsive to fluid resuscitation. Hypocalcemia can be treated with calcium gluconate supplementation. Monitoring with ionized calcium is recommended because of the low serum albumin that usually occurs in this population. Hyperglycemia is also a frequent issue in this population. Insulin continuous infusions may be necessary to allow for better glycemic control, frequent blood glucose monitoring, and rate adjustments. Subcutaneous administration of insulin may be hindered by lack of subcutaneous absorption because of fluid resuscitation and vasopressor therapies. Although not needed for initial management, nutrition support is necessary for wound healing and should be initiated within 48 hours if possible. Enteral nutrition is the preferred method for nutrition and patients should receive an adequate intake of vitamins A, C, and D along with zinc. Other adjunctive therapies, including hyperbaric oxygen (HBO) and intravenous immunoglobulin (IVIG) may be considered. However, these have a controversial and limited role for specific patients and should not be considered for initial management. Lastly, pain control is essential for comfort of the patient undergoing multiple surgical procedures. In addition, preemptive administration of short-acting opioids may be considered prior to dressing or wound VAC changes.

V. COMPARTMENT SYNDROME

Compartment syndrome in the extremity is an elevation of pressure within a myofascial compartment resulting in ischemia. It is most commonly seen in the setting of trauma, particularly fractures and crush injuries. However, it may also be caused in nontraumatic settings by bleeding (postoperative or spontaneous in a patient with a bleeding disorder or on anticoagulation, positioning during surgery or constricting wraps) or by increased intracompartmental fluid (extravasated intravenous fluid or medication, burn injury, rhabdomyolysis, ischemiareperfusion). Because of the inelasticity of the fascial compartment, anything that increases the mass within the compartment can result in this potentially devastating complication. Compartment syndrome most commonly occurs in the leg, specifically in the anterior compartment, followed by the forearm, but may occur in the arm, thigh, hand, or foot. Of note, compartment syndrome may also occur in the abdomen or less commonly chest wall, and abdominal compartment syndrome is covered in **Chapter 14**.

Unrecognized compartment syndrome can result in loss of limb viability requiring amputation or an ischemic contracture with loss of limb function. If not addressed emergently, compartment syndrome can lead to death. Rhabdomyolysis of the muscle within the compartment may cause hyperkalemia and acute kidney injury, which may result in the need for emergent hemodialysis or fatal arrhythmias.

Physiologic compartment pressure is 0–8 mm Hg; elevations above 30 mm Hg result in venous hypertension and progressive ischemia. Without treatment, irreversible tissue damage occurs within 6–8 hours. It is a limb-threatening and ultimately life-threatening emergency; the only cure is surgical.

A. Diagnosis

The most common early symptom of compartment syndrome is pain, especially with passive stretch of the muscles within that compartment. In contrast, the presence of pulses is not reassuring in ruling out the diagnosis of compartment syndrome. Pulselessness is a late symptom, and irreversible tissue damage frequently occurs before the patient loses his or her pulse.

The diagnosis of compartment syndrome is primarily a clinical one. A history of trauma, particularly tibial fractures or crush injuries, should raise suspicion for ensuing compartment syndrome. Patients with bleeding disorders or on anticoagulation are also at increased risk. The classic examination findings include “the 6 P’s”—pain, paresthesia, pallor, poikilothermia, paralysis, and pulselessness—and a tense or hardened compartment. However, these findings are rarely all present. Of these, the most common early symptom is pain, especially with passive stretch of the muscles within that compartment. However, as compartment syndrome progresses, pain may paradoxically decrease as nerve function becomes impaired. A high index of suspicion is critical to recognizing compartment syndrome early and maximizing the chance of successful intervention. Generally, the diagnosis can be made on clinical grounds alone. However, if physical examination is equivocal and compartment syndrome is suspected, compartment pressures may be measured using either commercial devices or an angiocath connected to a transducer (eg, arterial line). If the pressure within the compartment exceeds 30 mm Hg, emergent fasciotomy is indicated.

It is crucial to realize that pulselessness is a late finding in compartment syndrome because the systolic pressure will overcome the increased compartment pressure until very late in the progression of the disease. As such, a clinician should not be reassured by the presence of pulses and mistakenly rule out compartment syndrome because a patient has pulses; this action can lead to permanent disability or death.

B. Management

Compartment syndrome is a true surgical emergency. The treatment for compartment syndrome is immediate fasciotomy. Opening the compartment(s) allows for blood and fluid to be evacuated, soft-tissue expansion, and restoration of perfusion. The keys to successful management are prompt diagnosis and early surgical intervention. If compartment syndrome is suspected, immediate surgical consultation is required.

Uncommonly, compartment syndrome may be caused by external compression, so removal of any compressive dressings will reduce the extrinsic elevation of compartment pressure. Elevation of the affected extremity to the level of the heart may help venous return. Fasciotomy must be performed emergently to avoid irreversible tissue damage and further sequelae of compartment syndrome.

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Compartment syndrome is a surgical emergency that requires an immediate operation to avoid irreversible tissue damage, disability, and potentially death.

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Key Points

Surgical Soft-Tissue Complications and Urgencies

- Surgical wound infections are classified as superficial incisional, deep incisional, and organ/space infections. These infections occur within 30 days of the surgery.
- Physical examination remains the most important and reliable approach to diagnosis. Local examination findings of pain, swelling, erythema, purulent drainage, and wound dehiscence all suggest possible surgical site infection.
- Surgeries with more contamination are associated with more frequent wound complications and increased risk of postoperative infections.
- New serosanguinous drainage from a wound could be nothing more than a subcutaneous fluid collection or it could also herald a fascial dehiscence that might progress to evisceration. Prompt surgical consultation is warranted.
- Sternal wound dehiscence requires special attention because it is almost uniformly caused by infection and requires urgent debridement and reapproximation to prevent sternal nonunion or more serious mediastinal infection.
- Surgical consultation with early surgical debridement is the cornerstone for the management of NSTI. Delays in surgical management are associated with increased mortality and morbidity.
- Empiric antimicrobial therapy should be broad-spectrum to include gram-positive, gram-negative, and anaerobic pathogens with definitive therapies directed toward specific pathogens identified from microbiologic data.
- Compartment syndrome is a limb-threatening and ultimately life-threatening true surgical emergency. Irreversible tissue damage

occurs within 6–8 hours in compartment syndrome without treatment.

- Rhabdomyolysis of the muscle within the compartment may cause hyperkalemia and acute kidney injury, which may result in the need for emergent hemodialysis or fatal arrhythmias.
- A clinician should not be reassured by the presence of pulses and mistakenly rule out compartment syndrome because a patient has pulses; this action can lead to permanent disability or death.
- The treatment for compartment syndrome is immediate fasciotomy.

Suggested Readings

1. Berrios-Torres SI, Umscheid CA, Bratzler DW, et al. Centers for Disease Control and Prevention Guideline for the Prevention of Surgical Site Infection, 2017. *JAMA Surg*. 2017;152(8):784-791.
2. Bodansky D, Doorgakant A, Alsousou J, et al. Acute Compartment Syndrome: Do guidelines for diagnosis and management make a difference? *Injury*. 2018;49(9):1699-1702.
3. Fonder MA, Lazarus GS, Cowan DA, Aronson-Cook B, Kohli AR, Mamelak AJ. Treating the chronic wound: A practical approach to the care of nonhealing wounds and wound care dressings. *J Am Acad Dermatol*. 2008;58(2):185-206.
4. Keung EZ, Liu X, Nuzhad A, et al. Immunocompromised status in patients with necrotizing soft-tissue infection. *JAMA Surg*. 2013;148(5):419-426.
5. Psoinos CM, Flahive JM, Shaw JJ, et al. Contemporary trends in necrotizing soft-tissue infections in the United States. *Surgery*. 2013;153(6):819-827.

6. Sarani B, Strong M, Pascual J, Schwab CW. Necrotizing fasciitis: current concepts and review of the literature. *J Am Coll Surg*. 2009;208(2):279-288.
7. Sartelli M, Malangoni MA, May AK, et al. World Society of Emergency Surgery (WSES) guidelines for management of skin and soft tissue infections. *World J Emerg Surg*. 2014;9(1):57.
8. Schmidt A. Acute Compartment Syndrome. *Injury*. 2017;48(Suppl 1):S22-S25.
9. Stevens DL, Bisno AL, Chambers HF, et al. Practice guidelines for the diagnosis and management of skin and soft tissue infections: 2014 Update by the Infectious Diseases Society of America. *Clin Infect Dis*. 2014;59(2):147-159.
10. Stevens DL, Bryant AE. Necrotizing Soft-Tissue Infections. *N Engl J Med*. 2017;377:2253.
11. Ustin JS, Malangoni MA. Necrotizing soft-tissue infections. *Crit Care Med*. 2011;39(9):2156-2162.
12. Wong CH, Khin LW, Heng KS, Tan KC, Low CO. The LRINEC (Laboratory Risk Indicator for Necrotizing Fasciitis) score: a tool for distinguishing necrotizing fasciitis from other soft tissue infections. *Crit Care Med*. 2004;32(7):1535-1541.

Suggested Websites

1. CDC; https://www.cdc.gov/features/necrotizingfasciitis/index.html
2. CDC; Trends in US Hospital Admissions for Skin and Soft Tissue Infections https://wwwnc.cdc.gov/eid/article/15/9/08-1228_article
3. British Orthopaedic Association, BAoPRaAS, Royal College of Nursing. BOAST: Diagnosis and Management of Compartment Syndrome of the Limbs. Br Orthopaedic Assoc Stand Trauma, 2014. https://www.boa.ac.uk/resources/boast-10-pdf.html

Appendix 1

RAPID RESPONSE SYSTEM

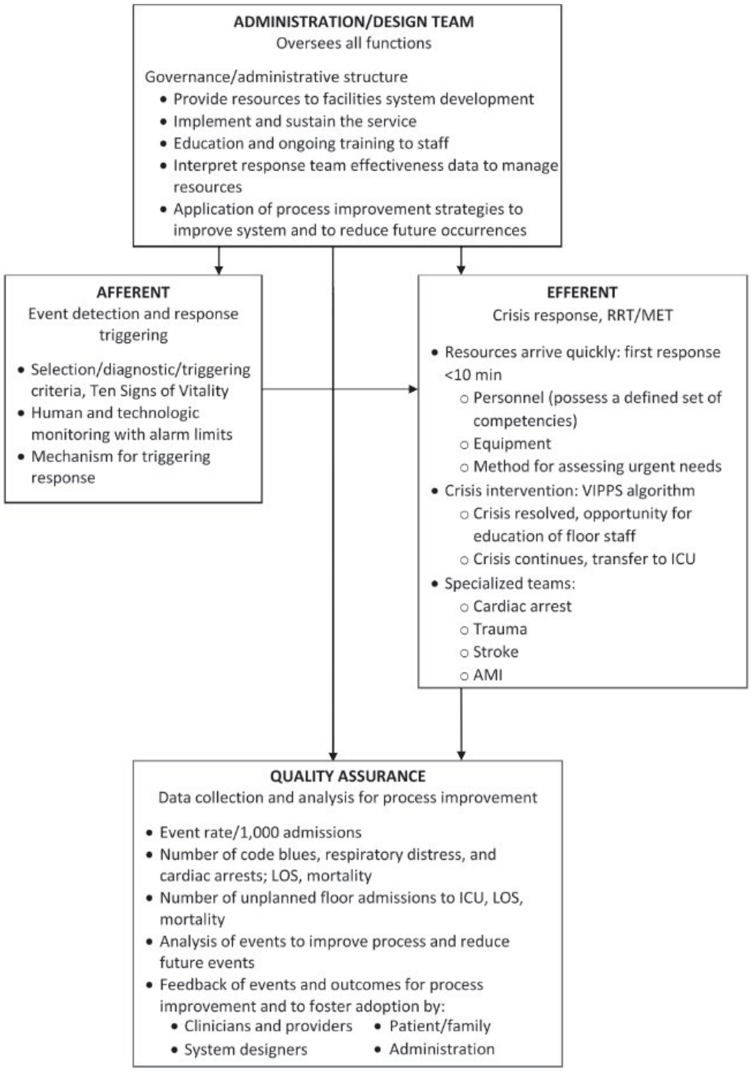
I. INTRODUCTION

Rapid response systems (RRS) have emerged as important resources that focus on the hospitalized patient with unexpected, sudden deterioration in a condition from any cause. Historically, crisis teams were activated only after a significant event, such as cardiac arrest; there was no organized approach to preventing an untoward event in an at-risk hospitalized patient. Most patients who experience a cardiac arrest while in the hospital demonstrate identifiable signs of deterioration in the previous 8 hours. Early recognition of deterioration and timely intervention can reduce the incidence of in-hospital cardiac arrest or the need for intensive care. RRSs have been shown to reduce in-hospital mortality and cardiopulmonary arrest, although the presence of a physician is not significantly associated with a mortality reduction.

Unfortunately, the early indicators of clinical deterioration can be difficult to identify. Assessing the physiologic reserve of a patient is challenging. RRSs bring additional experienced providers with advanced monitoring tools to the patient's bedside. If needed, more advanced monitoring and therapy can be initiated immediately, and a decision can be made about the most appropriate care level. The most important action in the process is the call for help.

The RRS model can be divided into four components, each of which plays an integral role in the success of the system (**Figure A1-1**). The administrative arm oversees appropriate staffing, provides resources, drafts protocols and guidelines, and ensures staff education regarding the presence and utility of the service. The afferent arm is concerned with detecting impending deterioration, while the efferent arm is focused on rendering therapy and mobilizing additional resources quickly. Lastly, the performance improvement arm seeks to identify recurrent patterns of deterioration and assess improvement in quality measures following system-wide interventions.

Figure A1-1. Rapid Response System Structure


ADMINISTRATION/DESIGN TEAM
Oversees all functions
Governance/administrative structure
• Provide resources to facilities system development
• Implement and sustain the service
• Education and ongoing training to staff
• Interpret response team effectiveness data to manage resources
• Application of process improvement strategies to improve system and to reduce future occurrences
AFFERENT
Event detection and response triggering
• Selection/diagnostic/triggering criteria, Ten Signs of Vitality
• Human and technologic monitoring with alarm limits
• Mechanism for triggering response
EFFERENT
Crisis response, RRT/MET
• Resources arrive quickly: first response <10 min
○ Personnel (possess a defined set of competencies)
○ Equipment
○ Method for assessing urgent needs
• Crisis intervention: VIPPS algorithm
○ Crisis resolved, opportunity for education of floor staff
○ Crisis continues, transfer to ICU
• Specialized teams:
○ Cardiac arrest
○ Trauma
○ Stroke
○ AMI
QUALITY ASSURANCE
Data collection and analysis for process improvement
• Event rate/1,000 admissions
• Number of code blues, respiratory distress, and cardiac arrests; LOS, mortality
• Number of unplanned floor admissions to ICU, LOS, mortality
• Analysis of events to improve process and reduce future events
• Feedback of events and outcomes for process improvement and to foster adoption by:
• Clinicians and providers
• Patient/family
• System designers
• Administration

Abbreviations: AMI, acute myocardial infarction; LOS, length of stay; MET, medical emergency team; RRT, rapid response team; VIPPS, ventilation infusion of volume, pressors/pump, pharmacy, and specific interventions Adapted from Sebat F, ed. *Designing, Implementing, and Enhancing a Rapid Response System*. Mount Prospect, IL: Society of Critical Care Medicine; 2009:41.

II. BUILDING A MEDICAL EMERGENCY OR RAPID RESPONSE TEAM

Rapid response teams (RRTs) represent an intuitively simple concept: When a patient demonstrates signs of imminent clinical deterioration, a team of providers is summoned to the bedside to immediately assess and treat the patient with the goal of preventing transfer to the ICU, cardiac arrest, or death. An RRT is the intervention limb of the RRS. By consensus, a medical emergency team (MET) is led by a prescribing clinician (physician or advanced practice provider), whereas an RRT is led by a nurse and/or respiratory therapist (nonprescribing clinician). However, most recently, these two terms have been used interchangeably.

A. Response Team Composition

Although there is no single perfect team composition, the most successful METs and RRTs have been developed by leveraging existing hospital resources and targeting particular at-risk patient populations. Multidisciplinary, physician-led teams (METs) are prevalent in academic centers with training programs. Nurse-led or nurse–respiratory therapist teams (RRTs) with physician backup (or medical control similar to the emergency medical services model) are more often found in community hospitals without training programs. Regardless of the team composition, effective teamwork skills are essential to the success of the program. The implementation of standardized protocols or standing orders allows the team to use evidence-based best practices to address commonly identified clinical issues. The RRS administrative leadership should develop these protocols and standing orders in accordance with institutional policies and procedures. Possible members of an MET or RRT are identified in **Table A1-1**.

Table A1-1 Possible Members of Medical Emergency or Rapid Response Team

Physicians (attending, fellow, resident)	Intensivist, hospitalist, emergency medicine physician, anesthesiologist, pulmonologist, surgeon, internist
Advanced practice providers	Nurse practitioner, physician assistant, certified registered nurse anesthetist
Nurses	ICU nurse, postanesthesia care unit nurse, emergency department nurse, telemetry unit nurse, nursing supervisor
Other providers	Respiratory therapist, electrocardiography technician, emergency medical technician/paramedic

At an academic hospital, the composition of the responding team may include the following combinations of caregivers:

- ICU attending and/or fellow, ICU nurse, respiratory therapist, pharmacist
- Hospitalist, medicine resident or advanced practice provider, ICU nurse, respiratory therapist
- ICU nurse, respiratory therapist, physician (backup)

At a non-teaching hospital, the team may consist of one of the following combinations:

- Emergency department physician or advanced practice provider, hospitalist, ICU nurse, respiratory therapist
- Emergency department nurse, ICU nurse, respiratory therapist
- Postanesthesia care unit nurse, respiratory therapist, physician (backup)

Typically, physician members are trained (or are training) in critical care, emergency medicine, anesthesia, or internal medicine. They bring their knowledge of critical illness and their skills in the management of life-threatening problems to the patient's bedside. Nurse members usually have many years of bedside experience and most often have extensive critical care training. Team members from other disciplines add value to the MET or RRT with their knowledge of such factors as airway and respiratory management, drug therapies, traumatic injury management, and critical care transport.

Team members usually are expected to maintain current provider status in basic and advanced cardiac life support, pediatric advanced life support (where applicable), and fundamental critical care. Periodic teamwork exercises in mock events or medical simulation centers can hone members' evaluation and management skills. Treatment protocols and standing orders should be reviewed and amended based on feedback from MET or RRT calls and quality improvement data.

B. Response Team Equipment

The use of advanced physiologic monitors and equipment by appropriately trained MET members can provide crucial support to the at-risk patient. This can greatly enhance the team's ability to evaluate and manage signs and symptoms of clinical deterioration. Clearly, the earlier clinical abnormalities are identified and addressed, the greater the potential for a positive outcome and, often, the simpler the needed intervention. The MET or RRT should first evaluate the resources that are readily available in the areas it will support and then create a list of additional needed equipment (**Table A1-2**). The response team must have access to cardiac, respiratory, and simple hemodynamic monitors. Other equipment and medications should be selected based on the patient populations served, the team composition, and local regulations and policies. Because the MET or RRT is expected to respond quickly, any additional necessary equipment and supplies should be organized in appropriate bags or carts that can be readily transported to the patient.

Table A1-2 Response Team Equipment List[a]

Physiologic Monitors
Monitor/defibrillator with external pacing capability
Noninvasive blood pressure device
Pulse oximetry
Portable capnography (if available)

Respiratory Equipment
Portable oxygen tank
Portable suction device
High-flow oxygen reservoir face mask
Bag-mask device
Ventimask®, nasal cannula, and simple face mask
Nebulizer mask
Oropharyngeal/nasopharyngeal airways
Laryngeal mask airways
Laryngoscopes and blades
Endotracheal tubes with stylets
Cricothyrotomy catheter kit
Stethoscope
Consider portable ultrasound machine where available

Cardiovascular Equipment
Manual blood pressure device
IV administration kits
IV kits

Miscellaneous
Personal protective equipment
Sterile gloves
Dressings and bandages
Antiseptics
Drug bag (as appropriate for scope of practice)
Vasopressors
Inotropes
Vasodilators
Sedatives and analgesics
Bronchodilators
Crystalloid and colloid IV fluid
Aspirin

[a] Necessary equipment and supplies should be available on the patient unit or carried by the team.

III. ACTIVATING THE MEDICAL EMERGENCY OR RAPID RESPONSE TEAM

A. Activation Criteria and Triggers

The most important activation criterion is the concern of the bedside physician, nursing staff, or family that something is wrong, even if other indicators are within acceptable limits. This intuition is often quite sensitive and warrants additional assessment. The fact that an intuition or a gut feeling is not very specific should not discourage activation of the MET or RRT.

The distribution of a predefined set of MET or RRT activation criteria may help to focus attention on important early indicators and empower the bedside staff to call for help early. These criteria may be based on the detection of acute changes in physiology, organ system–specific signs and symptoms, and event triggers (**Table A1-3**). Acute changes in physiology may include changes in vital signs that exceed predefined limits, such as tachycardia, tachypnea, hypotension, and oliguria.

Table A1-3 Models of Activation Criteria

Acute Physiologic Criteria

Acute change in heart rate to <40 or >130 beats/min
Acute change in systolic blood pressure to <90 mm Hg
Acute change in urine output to <50 mL in 4 hours
Acute change in respiratory rate <8 or >30 breaths/min
Acute change in pulse oximetry to <90% despite oxygen administration
Acute change in consciousness
Qualitative deterioration in clinical status

Organ System-Specific Criteria

Airway
    Respiratory distress
    Threatened airway

Breathing
    Respiratory rate >30 breaths/min
    Respiratory rate <6 breaths/min
    Spo_2 <90% on oxygen
    Difficulty speaking

Circulation
    Blood pressure <90 mm Hg despite treatment
    Pulse rate >130 beats/min

Neurology
    Any unexplained decrease in consciousness
    New agitation or delirium
    Repeated or prolonged seizures

Other
    Concern about the patient
    Uncontrolled pain
    Failure to respond to treatment
    Inability to obtain prompt assistance

Event Trigger

Unscheduled naloxone dose administered
Increase in oxygen requirement
    Any change to a 100% reservoir face mask
    Any change in Fio_2 delivery by ≥20%
After 3 unanswered pages to medical/surgical team for any patient in a shift
Response time to medical/surgical team page >30 min
Family concern about patient status
Any falls or traumatic injuries
Pain score ≥4 of 10 more than 30 min after highest ordered dose of analgesic
Persistent nausea/vomiting more than 30 min after highest does of antiemetic
Any newly noted abnormal pulse

Abbreviations: SpO_2, oxygen saturation on pulse oximetry; FIO_2, fraction of inspired oxygen.

The detection of one or more indicators of organ system dysfunction may trigger activation of the response team. Such pattern recognition may be more effective in detecting clinical deterioration when there is a gradual change in physiologic variables.

Event triggers help emphasize that some patient incidents or interventions warrant further evaluation. The event may be a sign or a result of a larger issue that could be an ongoing threat to the patient's safety. For example, any administration of naloxone is an indicator that one or more undesirable adverse effects of opiates may be present. Although naloxone may temporarily reverse these adverse effects, they can recur as the antagonist effects wane. A focused evaluation by the MET or RRT may avoid the undesirable consequences of these events.

B. Response Team Scoring Systems

The use of a scoring system in evaluating the at-risk patient can provide a graded assessment of clinical status and help to determine the level of response needed. An overall score is calculated based on the aggregate of points assigned to various symptoms, vital signs, and laboratory studies. Additional points are assigned to results that vary greatly from normal. Several patented early warning scoring systems are available, although not all are validated. The Modified Early Warning Score, which evaluates a patient's vital signs and mental status, has been validated in hospitalized medical patients. A score of 5 or greater has been associated with an increased mortality rate and increased incidence of ICU admission.

Individual MET or RRT programs may choose to define absolute value or trend thresholds that trigger a move to a higher level of care or mobilization of additional clinical resources. Collection and analysis of aggregate scores in patients receiving MET or RRT services can be used for quality improvement efforts, such as evaluation of standing orders, event cluster identification, and resource utilization.

IV. TEAM RESPONSE

A. Response Team Interventions

Interventions should be aimed at rapidly stabilizing the patient and preventing further deterioration or full arrest. Studies have shown that the ***three most common reasons for activating an MET or RRT are hypoxemia, hypotension, and altered mental status***. Teams should identify the primary activating events in their institutions and build protocols to address each rapidly.

Respiratory distress is the leading physiologic cause of MET or RRT activation. The reasons for acute changes can be related to fluid status, medications (eg, narcotics), progression of underlying disease, or patient noncompliance with physician-ordered oxygen therapies. Initial treatment is stabilization of the airway and application of high-flow oxygen to relieve the patient's distress and improve oxygen saturation. Following improvement in patient status, the team can evaluate for potential reversible causes.

Hypotension can be related to volume status (both overall volume and blood volume); medications, including narcotics and antihypertensives; and the potential for sepsis. Initial treatment is administration of fluids to raise systolic pressure and/or the immediate reversal of a known cause, such as narcotics. Consideration should be given to empiric antibiotic therapy in cases of suspected severe sepsis or septic shock.

Altered mental status is most often associated with hypoxemia, hypotension, or hypoglycemia. These should be evaluated and treated first. Altered mental status unrelated to those issues should be evaluated for either neurologic or medication causes. Treatment, including evaluation with computed tomography scanning, should be guided accordingly.

The responding team should make every effort to involve the patient's primary physician and rounding team in decisions regarding disposition and care. The role of a MET or RRT is not to take the place of the primary team but to act for – and with – them at the bedside in an emergency.

B. Response Team Communications

In the complex hospital environment, the use of a structured communication tool and a common critical language fosters the open communication among caregivers that is essential to the prompt evaluation and management of the at-risk patient. Incorporating the Situation, Background, Assessment, and Recommendation (SBAR) Tool into MET or RRT documentation can facilitate effective communication by gathering all pertinent data in one place for any discussions to follow. This tool has proven to be most valuable in the effective communication of critical information (**Table A1-4**).

Table A1-4 SBAR Communication Tool

Situation: *What is happening with the patient?*

Background: *What is the clinical background or context?*

Assessment: *What do I think is the problem?*

Recommendation/interventions: *What would I do to evaluate or correct it?*

C. Response Team Utilizing Attending Physician Expertise via Telemedicine

With telemedicine being widely used in institutions, providing early attending physician expertise via telemedicine can improve RRT evaluations. In a quasi-experimental study done in a single center, RRTs used a smart phone-based telemedicine platform to facilitate early co-assessment and disposition at the patient's bedside with the ICU attending. Results showed that the RRT providers spent less time outside the ICU, and among patients transferred to the ICU there was a significant decrease in the likelihood of patients requiring vasopressors or intubation within the first 60 minutes of transfer. Utilizing early ICU attending involvement can improve efficiency of the RRT evaluations.

D. Response Team Education

One of the primary goals of METs and RRTs is education. The detection limb of the RRS model relies heavily on the early recognition of signs and symptoms of clinical deterioration. Regularly scheduled staff in-services and mock-event drills are effective in maintaining competencies in identifying the at-risk patient. Public posting and discussion of activation criteria can further enhance the use of MET or RRT services and reduce patient clinical crises. Review of aggregate quality improvement data from response team activity also can reinforce education. Post hoc review of a patient event with the entire unit staff after an MET or RRT call serves to raise the collective knowledge and skill of the entire group. This may reduce the likelihood of subsequent problems and increase the likelihood that signs and symptoms of clinical deterioration will be detected at the earliest indication in future patients. Topic-of-the-week presentations, MET or RRT case reviews, and SBAR practice sessions are examples of targeted educational activities.

V. STRATEGIES FOR SUCCESS

Hospitals that use an RRS report various factors that lead to successful team implementation. Some common themes in their success include:

1. Training/Education – The MET or RRT members and the bedside nursing staff must understand when and how to activate the team and the scope of team capabilities. The response team members will need ongoing training in management of common indicators in at-risk patients and effective intervention and communication strategies. The mentoring of the bedside nursing staff in critical assessment skills and effective communication skills is a primary team education objective. High-fidelity simulation in a simulation center is helpful, but low-fidelity simulations with mock medical emergency scenarios or table-top exercises are effective as well. Scenario-based case presentations using a chalkboard or paper can be offered in any clinical setting.
2. Equipment/Supplies – The equipment and supplies carried by the response team should be tailored to the needs of the patient population served, but then standardized to ensure that the

appropriate resources reach the bedside with each call. If multiple RRT bags are used, the items should be organized within each bag to facilitate rapid access at the bedside. It is impractical to carry every item available in the ICU. Equipment use should be reviewed as part of the quality improvement program. Seldom-used items should be removed unless they serve an important role in the management of infrequent, but high-risk events. The response team should strive to carry only the necessary equipment and supplies.

3. Culture of Empowerment – Staff nurses should be trained to recognize signs of clinical deterioration before a crisis and to trust their experience and skills. They should be empowered, and supported by leadership, to activate the MET or RRT according to established criteria. There should be no penalty for activating the MET or RRT, especially if the findings do not point to an impending clinical crisis. Such events can identify areas for targeted education in the detection of signs of clinical deterioration or focused review of the risks inherent to that patient population.

4. Evaluation – Data collection should be embedded into the clinical workflow to facilitate monitoring of clinical and service outcomes. Regular reporting, monitoring, and evaluation of response team activities and outcomes guide rapid cycle improvement of team processes. Patient and family satisfaction data help prioritize program development and resource allocation. Constant dialogue among the stakeholders to identify improvement opportunities is essential.

VI. SUMMARY

Hospitalized patients can be at risk for clinical deterioration in part because of the complex nature of healthcare delivery systems. The goal of the RRS model is to identify and manage signs and symptoms of clinical deterioration in at-risk patients through detection strategies at the bedside and mobilization of appropriate resources. Important factors in the successful implementation of an RRS include: (1) appropriate team composition; (2) activation criteria based on bedside staff concern, acute changes in physiology, or the use of scoring systems to identify at-risk patients; (3) interventions aimed at rapidly stabilizing the patient; (4) effective communication strategies like SBAR; (5) ongoing education to enhance detection and management of potential clinical crises; (6) availability of appropriate advanced clinical monitors, equipment, and medications to conduct MET or RRT activities; and (7) evaluation and correction of processes and causes of patient risk.

Suggested Readings

1. Bellomo R, Goldsmith D, Uchino S, et al. A prospective before-and-after trial of a medical emergency team. *Med J Aust*. 2003;179:283-287.

2. Buist MD, Moore GE, Bernard SA, et al. Effects of a medical emergency team on reduction of incidence of and mortality from unexpected cardiac arrests in hospital: preliminary study. *BMJ*. 2002;324:387-390.

3. Chen Q, Hawker F. Modifications to predefined rapid response team calling criteria: prevalence, characteristics and associated outcomes. *Critical Care Resus*. 2020;22(1):86.

4. DeVita MA, Bellomo R, Hillman K, et al. Findings of the first consensus conference on medical emergency teams. *Crit Care Med*. 2006;9:2463-2478.

5. DeVita MA, Hillman K, Bellomo R, eds. *Medical Emergency Teams: Implementation and Outcome Measurement*. New York, NY: Springer Science + Business Media Inc; 2006.

6. Fiero M, Rosenblatt S, Zhang B, Synder M, et al. Providing early attending physician expertise via telemedicine to improve rapid response team evaluations. *Pediatr Crit Care Med*. 2020;21(5):e221-e227.

7. Halvorsen L, Garolis S, Wallace-Scroggs A, Stenstrom J, Maunder R. Building a rapid response team. *AACN Adv Crit Care*. 2007;18:129-140.

8. Leonard M, Graham S, Bonacum D. The human factor: the critical importance of effective teamwork and communication in providing safe care. *Qual Saf Health Care*. 2004;13(suppl 1):i85-i90.

9. Maharaj J, Raffaele I, Wendon J. Rapid response systems: a systematic review and meta-analysis. *Crit Care*. 2015;19(1):254.

10. Murray T, Kleinpell R. Implementing a rapid response team: factors influencing success. *Crit Care Nurse Clin North Am*. 2006;18:493-501.

11. Sebat F, ed. *Designing, Implementing, and Enhancing a Rapid Response System*. Mount Prospect, IL: Society of Critical Care Medicine; 2009.

12. Sebat F, Musthafa AA, Johnson D, et al. Effect of a rapid response system for patients in shock on time to treatment and mortality during 5 years. *Crit Care Med*. 2007;35:2568-2575.

13. Subbe CP, Kruger M, Rutherford P, Gemmel L. Validation of a modified Early Warning Score in medical admissions. *QJM*. 2001;94(10):521-526.

14. Thomas K, VanOyen Force M, Rasmussen D, Dodd D, Whildin S. Rapid response team: challenges, solutions, benefits. *Crit Care Nurse*. 2007;27(1):20-27.

15. Tirkkonan J, Skrifivars M, Parr M, Tamminen T, Aneman A. In hospital cardiac arrest in hospitals with mature rapid response systems – A multicenter retrospective cohort study. *Resuscitation*. 2020;149:109-116.

Suggested Website

1. American College of Cardiology. http://www.acc.org.

Appendix 2

ARTERIAL BLOOD GAS ANALYSIS AND TREATMENT

These acid-base problems are provided for practice in analyzing arterial blood gas and electrolyte information and determining appropriate interventions.

For complicated acid-base disorders, it may be helpful to understand the utility of the delta gap (Δgap). In an uncomplicated anion gap (AG) metabolic acidosis, every AG increase of 1 mmol/L beyond the normal value should result in a concomitant decrease of approximately 1 mmol/L in [HCO_3]. Deviation from this relationship suggests a mixed acid-base disorder. The difference between the change in the AG and the change in [HCO_3] from the normal values is the Δgap, which can be expressed as:

$$\Delta\text{gap} = (\text{deviation of AG from normal}) - (\text{deviation of } [HCO_3] \text{ from normal})$$

The normal value for Δgap should be 0. However, variance in measurements can result in a Δgap of 0 ± 6. If the Δgap is positive, then a simultaneous metabolic alkalosis exists. If the decrease in [HCO_3] is greater than the increase in AG, which results in a negative Δgap, then a concomitant normal AG acidosis (hyperchloremic) may exist. Small deviations of the Δgap may not indicate mixed acid-base disorders, and clinical information must always be considered.

For purposes of analyzing the following cases, assume that a normal HCO_3 is 24 mmol/L and a normal AG is 12 mmol/L using the formula:

$$[Na] - ([Cl] + [HCO_3])$$

Case 1

A 78-year-old woman with hypertension and hyperlipidemia is admitted to the intermediate care unit for ongoing evaluation and management of a community-acquired pneumonia. She was admitted 12 hours ago from the emergency department. She remains tachypneic with increased work of breathing. Vital signs are: heart rate 105 beats/min, blood pressure 110/68 mm Hg, respiratory rate 22 breaths/min, and temperature 38.4°C (101.2°F). Physical examination reveals bilateral rhonchi and normal mental status. She is receiving supplemental oxygen at 3 L/min via nasal cannula, and oxygen saturation on pulse oximetry is 88%. An arterial blood gas measurement is made as part of her ongoing workup, with the following results:

pH 7.47

$PaCO_2$ 31 mm Hg (4.13 k Pa)

PaO_2 55 mm Hg (7.33 k Pa)

HCO_3 (calculated) 22 mmol/L

1a. Which one of the following best describes the acid-base disorder?

A. Metabolic acidosis

B. Respiratory alkalosis

C. Respiratory alkalosis and metabolic acidosis

D. Respiratory alkalosis and metabolic alkalosis

1b. Which one of the following is the most appropriate intervention?

A. Intubation and mechanical ventilation

B. Noninvasive ventilation

C. Increase in supplemental oxygen concentration

D. No new intervention

Case 2

A 26-year-old man arrives at the emergency department with multisystem trauma following a motorcycle collision. He is somnolent with a Glasgow Coma Scale score of 13. The primary survey reveals an open airway with equal breath sounds bilaterally. Vital signs are: temperature 36.2°C (97.2°F), heart rate 116 beats/min, respiratory rate 20 breaths/min, blood pressure 100/50 mm Hg, and oxygen saturation on pulse oximetry 99% with a non-rebreather mask in place. The patient undergoes diagnostic radiological evaluations that reveal left rib fractures without hemothorax or pneumothorax. As part of his initial workup, he has blood sent for laboratory analysis. The results are as follows:

pH 7.31
$PaCO_2$ 32 mm Hg (4.27 k Pa)
PaO_2 163 mm Hg (21.73 k Pa)
Na 140 mmol/L
Cl 105 mmol/L
HCO_3 15 mmol/L

2a. Which acid-base disorder is present?

A. Non-anion gap metabolic acidosis

B. Respiratory acidosis

C. Anion gap metabolic acidosis

D. Metabolic acidosis with respiratory alkalosis

2b. What is the suspected cause of the acid-base disorder?

A. Diabetic ketoacidosis

B. Lactic acidosis

C. Uremia

D. Hyperventilation

2c. Which of the following is the most appropriate intervention?

A. Administration of intravenous bicarbonate

B. Fluid and blood product administration

C. No intervention required at this time

D. Intubation

Case 3

A 21-year-old female college student did not wake up the morning after attending a fraternity party where alcohol and drugs were available. Emergency services was called, the patient was placed on supplemental oxygen via non-rebreather mask, peripheral intravenous access was obtained, and fluids were started. Initial vital signs in the emergency department are: heart rate 102 beats/min, respiratory rate 10 breaths/min, blood pressure 92/60 mm Hg, and oxygen saturation on pulse oximetry 94%. The patient only moans when exposed to noxious stimuli but does localize. Blood is drawn for laboratory evaluation, including an arterial blood gas. The result are as follows:

pH 7.23

$PaCO_2$ 60 mm Hg (8.0 k Pa)

Na 141 mmol/L

K 4.0 mmol/L

Cl 110 mmol/L

HCO_3 26 mmol/L

3a. Which acid-base disorder is present?

A. Non-anion gap metabolic acidosis

B. Respiratory acidosis

C. Respiratory acidosis and non-anion gap metabolic acidosis

D. Respiratory acidosis and metabolic alkalosis

3b. Which of the following should be the initial intervention?

A. Intubation and intravenous administration of naloxone

B. Administration of activated charcoal

C. Noninvasive positive pressure ventilation

D. No additional intervention

Case 4

A 55-year-old man is admitted to the surgical ICU after elective laparoscopic cholecystectomy. An iatrogenic injury to the hepatic artery required conversion to an open cholecystectomy and fluid resuscitation with normal saline and blood products. Vital signs are: heart rate 115 beats/min, respiratory rate 12 breaths/min (ventilator rate), blood pressure 105/68 mm Hg, and oxygen saturation on pulse oximetry 99% at fraction of inspired oxygen of 50%. Laboratory values are as follows:

pH 7.32
$PaCO_2$ 36 mm Hg (4.8 k Pa)

Na 146 mmol/L
K 3.8 mmol/L
Cl 117 mmol/L
HCO_3 18 mmol/L

4a. Which acid-base disorder is present?

A. Anion gap metabolic acidosis

B. Anion gap metabolic acidosis and respiratory acidosis

C. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

D. Non-anion gap metabolic acidosis

4b. Which of the following is the most likely cause of the acid-base disorder in this patient?

A. Cardiogenic shock

B. Hemorrhagic shock

C. Normal saline administration

D. Hypoventilation

Case 5

An 81-year-old man was admitted to the medical floor for an exacerbation of congestive heart failure. He received high-dose intravenous furosemide over the last 48 hours, which allowed him to be weaned off noninvasive positive pressure ventilation. He is currently on supplemental oxygen via nasal cannula. Vital signs are: heart rate 88 beats/min, respiratory rate 18 breaths/min, blood pressure 120/72 mm Hg, and oxygen saturation on pulse oximetry 97% on supplemental oxygen at 6 L/min. Laboratory values are as follows:

pH 7.50
$PaCO_2$ 45 mm Hg (5.87 k Pa)
Na 136 mmol/L
Cl 96 mmol/L
HCO_3 33 mmol/L

5a. Which acid-base disorder is present?

A. Metabolic alkalosis and respiratory acidosis

B. Metabolic alkalosis

C. Metabolic alkalosis and non-anion gap acidosis

D. Respiratory acidosis

5b. Which of the following is the most likely cause of the acid-base disorder?

A. Hypercapnic respiratory failure

B. Volume overload related to congestive heart failure

C. Hypercortisolism

D. Diuretic administration

5c. Which of the following is an appropriate treatment option?

A. Restart noninvasive positive pressure ventilation

B. Administer acetazolamide

C. Continue diuresis with furosemide

D. Decrease administration of furosemide and consider administration of fluids

Case 6

A 58-year-old woman with hypertension and chronic kidney disease is admitted to the hospital with alcohol intoxication. She is somnolent and arouses to painful stimuli. Vital signs are: heart rate 110 beats/min, blood pressure 142/88 mm Hg, respiratory rate 10 breaths/min, temperature 37°C (98.6°F), and oxygen saturation on pulse oximetry 94%. Laboratory results are as follows:

pH 7.23

$PaCO_2$ 38 mm Hg (5.06 k Pa)

PaO2 78 mm Hg (10.4 k Pa)

Na 134 mmol/L

K 6.1 mmol/L

Cl 100 mmol/L

HCO_3 15 mmol/L

Blood urea nitrogen 62 mg/dL

Creatinine 3.7 mg/dL

Glucose 125 mg/dL

6. Which one of the following best describes the acid-base disorder?

A. Anion gap metabolic acidosis

B. Anion gap metabolic acidosis and metabolic alkalosis

C. Anion gap metabolic acidosis and respiratory acidosis

D. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

Case 7

An 80-year-old man with hypertension, diabetes, and malnutrition is admitted to the hospital with cough, fever, and hypotension. Chest radiograph shows a right lower lobe pneumonia. Vital signs are: heart rate 115 beats/min, blood pressure 90/52 mm Hg, respiratory rate 20 breaths/min, temperature 38.3°C (101°F), and oxygen saturation on pulse oximetry 95% on oxygen supplemented at 8 L/min via nasal cannula. Laboratory results are as follows:

pH 7.35

$PaCO_2$ 32 mm Hg (4.27 k Pa)

PaO_2 78 mm Hg (10.4 k Pa)

Na 132 mmol/L

K 4.0 mmol/L

Cl 103 mmol/L

HCO_3 17 mmol/L

Blood urea nitrogen 20 mg/dL

Creatinine 1.4 mg/dL

Albumin 1.5 g/dL

7. Which one of the following best describes the acid-base disorder?

A. Anion gap metabolic acidosis

B. Non-anion gap metabolic acidosis

C. Non-anion gap metabolic acidosis and respiratory alkalosis

D. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

Case 8

A 60-year-old man with arterial vascular disease and hypertension presented to the emergency department with complaints of shortness of breath and abdominal pain. Vital signs are: heart rate 90 beats/min, blood pressure

168/96 mm Hg, respiratory rate 25 breaths/min, temperature 37.2°C (99°F), and oxygen saturation on pulse oximetry 98% while receiving oxygen at 2 L/min via nasal cannula. Laboratory results are as follows:

pH 7.55
$PaCO_2$ 15 mm Hg (2.0 k Pa)
PaO_2 98 mm Hg (13.07 k Pa)

Na 135 mmol/L
K 3.8 mmol/L
Cl 101 mmol/L
HCO_3 13 mmol/L

8a. Which one of the following best describes the acid-base disorder?

A. Acute respiratory alkalosis

B. Chronic respiratory alkalosis

C. Acute respiratory alkalosis and metabolic alkalosis

D. Acute respiratory alkalosis and metabolic acidosis

8b. Which one of the following is a potential etiology of the acid-base disorder?

A. Pulmonary embolism

B. Sepsis

C. Diuretics

D. Chronic obstructive lung disease and renal failure

Case 9

A 70-year-old woman is admitted to the ICU with syncope after several days of vomiting. Vital signs are: heart rate 140 beats/min, blood pressure 80/50 mm Hg, respiratory rate 24 breaths/min, and temperature 37.0°C (98.6°F). Laboratory results are as follows:

pH 7.30
$PaCO_2$ 36 mm Hg (4.8 k Pa)

Na 138 mmol/L
K 3.0 mmol/L
Cl 93 mmol/L

PaO_2 88 mm Hg (11.73 k Pa)

HCO_3 20 mmol/L

Glucose 90 mg/dL

9. Which one of the following best describes the acid-base disorder?

A. Anion gap metabolic acidosis

B. Anion gap metabolic acidosis and metabolic alkalosis

C. Anion gap metabolic acidosis and respiratory acidosis

D. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

Case 10

A 55-year-old diabetic, hypertensive man presents with nausea, vomiting, and abdominal pain. Vital signs are: heart rate 124 beats/min, blood pressure 102/50 mm Hg, respiratory rate 22 breaths/min, and temperature 36.4°C (97.6°F). Laboratory results are as follows:

pH 7.45
PaCO_2 34 mm Hg (4.53 k Pa)
PaO_2 85 mm Hg (11.33 k Pa)

Na 134 mmol/L
K 3.2 mmol/L
Cl 85 mmol/L
HCO_3 23 mmol/L

Glucose 420 mg/dL

10. Which one of the following best describes the acid-base disorder?

A. Respiratory acidosis and metabolic acidosis

B. Respiratory acidosis, metabolic acidosis, and metabolic alkalosis

C. Respiratory alkalosis, metabolic acidosis, and metabolic alkalosis

D. Respiratory alkalosis and metabolic acidosis

CASE STUDY ANSWERS AND RATIONALES

Case 1

1a. The correct answer is B, Respiratory alkalosis.

The pH is alkalemic. The low $PaCO_2$ suggests a respiratory process rather than a metabolic process. The formula to determine if the respiratory process is acute is:

$$\text{Increase in pH} = 0.08 \times \frac{(40 - \text{Paco}_2)}{10}$$

Using the information from the case, the expected increase in pH would be 0.072, resulting in an expected pH 7.47. This finding suggests a pure respiratory process. You can further analyze it by considering whether there is appropriate buffering of HCO_3 using the following formula:

$$\text{Decrease in } [\text{HCO}_3] = 2 \times \frac{\Delta\text{Paco}_2}{10}$$

Data from the blood gas measurements suggest a decrease of $[HCO_3]$ of 1.8 mmol/L, which is close to the decrease of 2 mmol/L of the calculated $[HCO_3]$.

Although the patient is at risk for a metabolic acidosis, the appropriate decrease of $[HCO_3]$ in relation to the respiratory alkalosis makes that a less likely condition. Clinically, you would always review the electrolytes along with the arterial blood gas and calculate the anion gap. There is no suggestion of a metabolic alkalosis with the near normal $[HCO_3]$.

1b. The correct answer is C, Increase in supplemental oxygen concentration.

The patient is significantly hypoxic but based solely on the information presented, she may not need any more support than an increase in oxygen concentration and continued monitoring. Any worsening of her respiratory rate or mental status may necessitate positive pressure support.

Case 2

2a. The correct answer is C, Anion gap metabolic acidosis.

The pH is acidemic. The low bicarbonate concentration is consistent with a metabolic process. The next step is to determine if appropriate respiratory compensation is present.

Appropriate $PaCO_2$ compensation = 1.5 x $[HCO_3]$ + 8 ± 2

In this case, the appropriate compensation would yield $PaCO_2$ 30.5 ± 2 mm Hg. Thus, respiratory compensation is appropriate. The next step is to calculate the anion gap.

$AG = [Na] – ([Cl] + [HCO_3])$

AG for this case = [140] – [(105+15)] = 20 mmol/L

This patient has an elevated anion gap metabolic acidosis. With an anion gap acidosis, the Δgap should be calculated to determine if additional metabolic processes are present.

Δgap = (deviation of AG from normal) – (deviation of $[HCO_3]$ from normal)
= (20-12) – (24-15)
= -1 mmol/L

This is within the normal range of 0 + 6, indicating that no additional metabolic process is present.

2b. The correct answer is B, Lactic acidosis.

The causes of elevated anion gap metabolic acidosis can be remembered with the following mnemonic MUDPILES, which stands for methanol, uremia, diabetic ketoacidosis, paracetamol/acetaminophen, isoniazid, lactic acidosis, ethylene glycol or methanol, and salicylates.

This case depicts a trauma patient in shock with hypoperfusion, resulting in lactic acidosis.

2c. The correct answer is B, Fluid and blood product administration.

The goal is restore perfusion to the tissues. This patient is experiencing hypovolemic hemorrhagic shock. The treatment is fluid and blood product administration and control of the hemorrhage.

Case 3

3a. The correct answer is B, Respiratory acidosis.

The pH is acidemic. The increase in $PaCO_2$ indicates a respiratory process. Next, determine if this is an acute or chronic respiratory process.

For an acute respiratory acidosis, the decrease in $pH = 0.08 \times \frac{\Delta Paco_2}{10}$

Thus, the decrease in $pH = 0.08 \times 20/10 = 0.16$, which is close to the observed value of 60 mm Hg (8.0 k Pa). This is an acute respiratory process.

If metabolic compensation is present, the bicarbonate concentration will increase 1 mmol/L for every 10 mm Hg (1.33 k Pa) increase in $PaCO_2$. For this case, there is a 20 mm Hg change in $PaCO_2$ that should translate into a 2 mmol/L increase in bicarbonate. The HCO_3 concentration is 26 mmol/L, which is 2 mmol/L above the normal value of 24 mmol/L and consistent with appropriate metabolic compensation.

3b. The correct answer is A, Intubation and intravenous administration of naloxone

This patient has hypoventilation related to drug and alcohol intoxication. Activated charcoal will not reverse the respiratory depression. The patient also was not found until the following morning, making it too late for use of activated charcoal. The severely depressed mental status prohibits the use of noninvasive positive pressure ventilation; a patient must be conscious with the ability to protect the airway for noninvasive positive pressure ventilation to be used. This patient should be intubated to control her respiratory failure, and naloxone can be administered simultaneously.

Case 4

4a. The correct answer is D, Non-anion gap metabolic acidosis.

The correct answer is D, Non-anion gap metabolic acidosis.

The pH is academic and the change in HCO_3 concentration would indicate a metabolic process. The next step is to evaluate whether the respiratory compensation is appropriate.

Respiratory compensation: $1.5 \times [HCO_3] + 8 \pm 2$

Respiratory compensation: $1.5 \times [18] + 8 \pm 2 = 35 \pm 2$

In this case the patient has appropriate respiratory compensation. The next step is to determine if the anion gap is elevated.

$$AG = [Na] - ([Cl] + [HCO_3])$$
$$146 - (117 + 18) = 11 \text{ mmol/L}$$

There is no elevation in the anion gap, so this patient has a non-anion gap metabolic acidosis.

4b. The correct answer is C, Normal saline administration.

Metabolic acidosis with a normal anion gap, which is a hyperchloremic acidosis, may result from gastrointestinal or renal loss of HCO_3 or volume resuscitation with normal saline. In this case, the patient received excess fluid resuscitation due to hemorrhage in surgery. This patient has metabolic acidosis as a result of hyperchloremia from normal saline resuscitation.

Cardiogenic shock and hemorrhagic shock would result in metabolic acidosis with an elevated anion gap. Hypoventilation would be associated with a respiratory acidosis. The appropriate intervention is to change to an intravenous fluid with lower chloride content, such as Ringer lactate.

Case 5

5a. The correct answer is B, Metabolic alkalosis.

The pH is alkalemic. The increase in $[HCO_3]$ indicates a metabolic process. Respiratory compensation in metabolic alkalosis is determined by the following formula:

Increase in $PaCO_2$ = 0.6-0.7 x $\Delta[HCO_3]$ = 0.6-0.7 x 9 = 5.4-6.3 mm Hg (0.72-0.84 k Pa)

Thus, the increase in $PaCO_2$ is appropriate respiratory compensation. Calculation of the anion gap yields a normal result of 7 mmol/L.

5b. The correct answer is D, Diuretic administration.

Metabolic alkaloses are usually characterized as chloride-depleted (hypovolemic) or chloride-expanded (hypervolemic). In this patient, diuretic use is the most likely cause of the alkalosis.

5c. The correct answer is D, Decrease administration of furosemide and consider administration of fluids.

Chloride-depleted metabolic alkalosis is corrected by administration of an intravenous normal saline infusion. Discontinuation of the furosemide should occur to prevent further depletion of chloride and further exacerbation of metabolic alkalosis. Careful monitoring of the fluid status is indicated in a patient with history of heart failure, and expert consultation is required.

Case 6

6. The correct answer is C, Anion gap metabolic acidosis and respiratory acidosis.

The pH is acidemic and the low $[HCO_3]$ indicates a metabolic process. The formula for determining the expected respiratory compensation is:

$PaCO_2 = 1.5 \times [HCO_3] + 8 \pm 2$

The expected $PaCO_2$ would be approximately 30 mm Hg (4.0 k Pa). Thus, the finding of a higher $PaCO_2$ than expected indicates another acid-base process of respiratory acidosis. The respiratory acidosis is most likely secondary to depressed respiratory drive from intoxication. This patient has ventilatory insufficiency and must be monitored closely for worsening and the potential need for more aggressive ventilatory support. The anion gap is calculated as an increased value of 19 mmol/L, which is likely secondary to chronic kidney disease, but other unmeasured anions (such as lactate) may be contributing.

The Δgap can be calculated for this case. The deviation of the anion gap from normal is 7 mmol/L, and the deviation of the $[HCO3_3]$ from normal is 9 mmol/L. The difference of -2 mmol/L is not likely to represent a third acid-base process.

Case 7

7. The correct answer is A, Anion gap metabolic acidosis.

The pH is acidemic and the low $[HCO_3]$ indicates a metabolic process. The formula for determining the expected respiratory compensation is:

$$PaCO_2 = 1.5 \text{ x } [HCO_3] + 8 \pm 2$$

Thus, the expected $PaCO_2$ would be approximately 33 mm Hg (4.4 k Pa). The anion gap is calculated as 12 mmol/L, which appears normal. However, the albumin concentration must be taken into account. A limitation of the traditional approach to acid-base analysis is the effect of hypoalbuminemia on the anion gap. The expected anion gap decreases by 2.5 to 3 mmol/L for every 1 g/dL. In this patient, an albumin of 1.5 g/dL (assuming a normal albumin of 4 g/dL) would decrease the expected anion gap to 5 to 6 mmol/L. Thus, the calculated anion gap of 12 mmol/L is increased by 6 mmol/L. It is important to recognize the presence of the anion gap metabolic acidosis in assessing the severity of illness of this patient. The clinical scenario is consistent with severe sepsis, and a lactic measurement is indicated.

Case 8

8a. The correct answer is D, Acute respiratory alkalosis and metabolic acidosis.

The pH is alkalemic and the low $PaCO_2$ indicates a respiratory process. The next step is to determine if this is an acute or chronic respiratory alkalosis. The formula for acute respiratory alkalosis is:

Increase in pH $= 0.08 \times (40 - PaCO_2)/10$

Using the data from this case, the expected increase in pH would be 0.2 or pH 7.6, which is higher than 7.55. The formula for chronic respiratory alkalosis is:

Increase in pH $= 0.03 \times (40 - PaCO_2)/10$,

Applying it yields a pH increase of 0.075 or pH 7.475. These calculations suggest that there is likely to be a second acid-base disorder present. Calculation of the anion gap as 21 mmol/L identifies the second process of anion gap metabolic acidosis. The Δgap can be also be calculated for this case. The deviation of the anion gap from normal is 9 mmol/L, and the deviation of the $[HCO_3]$ from normal is 11 mmol/L. The difference of -2 is not likely to represent a third acid-base process.

8b. The correct answer is B, Sepsis.

The acid-base pattern can be helpful in suggesting an etiology of a patient's condition. In this case, respiratory alkalosis with anion gap metabolic acidosis is the typical acid-base disorder of sepsis. Salicylate intoxication would also be associated with this acid-base pattern. Pulmonary embolism would typically result in a respiratory alkalosis, with acidosis being unlikely in a hemodynamically stable patient. Diuretic use would primarily result in metabolic alkalosis rather than acidosis.

Chronic obstructive lung disease and renal failure would most likely result in a respiratory acidosis and metabolic acidosis.

Case 9

9. The correct answer is B, Anion gap metabolic acidosis and metabolic alkalosis.

The pH is acidemic and the lower HCO_3 indicates a metabolic process. The formula for determining the expected respiratory compensation is:

$PaCO_2 = 1.5 \times [HCO_3] + 8 \pm 2$

Using this, the expected $PaCO_2$ would be approximately 38 mm Hg (5.07 k Pa), which is close to the $PaCO_2$ of 36 mm Hg (4.8 k Pa). The anion gap is calculated as 25 mmol/L, which identifies the presence of an anion gap metabolic acidosis. The Δgap should also be calculated for this case. The deviation of the anion gap from normal is 13 mmol/L, and the deviation of the $[HCO_3]$ from normal is 4 mmol/L. The difference of 9 mmol/L suggests the presence of a metabolic alkalosis. The $[HCO_3]$ did not decrease as much as expected for the degree of acidosis. The clinical scenario is also suggestive of volume depletion from vomiting, resulting in the metabolic alkalosis. An anion gap metabolic acidosis (lactic acidosis) was the result of hypotension.

Case 10

10. The correct answer is C, Respiratory alkalosis, metabolic acidosis, and metabolic alkalosis.

The pH in this very ill patient is nearly normal, which should immediately raise the suspicion for complex acid-base disorders. The history is suggestive of possible diabetic ketoacidosis, so the first calculation could be the anion gap, which is increased at 26 mmol/L. Using the formula for determining the expected respiratory compensation for a metabolic acidosis—$PaCO_2 = 1.5 \times [HCO_3] + 8 \pm 2$—the expected $PaCO_2$ would be approximately 42 mm Hg (5.60 k Pa). Since the patient's $PaCO_2$ is lower at 34 mm Hg (4.53 k Pa), a respiratory alkalosis is present. The Δgap should definitely be calculated for this case. The deviation of the anion gap from normal is 14 mmol/L, and the deviation of the [HCO_3] from normal is 1 mmol/L. The difference of 13 mmol/L suggests the presence of a metabolic alkalosis. The [HCO_3] did not decrease as much as expected for the degree of acidosis. The clinical scenario is consistent with diabetic ketoacidosis with volume depletion from vomiting and a respiratory alkalosis, possibly secondary to pain.

You could also approach the problem by identifying the pH as alkalemic. The lower $PaCO_2$ would prompt assessment of whether it is an acute or chronic respiratory process. Acute is more likely, so the formula for acute respiratory alkalosis would be used: Increase in pH $= 0.08 \times (40 - PaCO_2)/10$. Based on the data from this case, the expected increase in pH would be 0.048 or pH 7.45, which is similar to the patient's value. The other acid-base processes would still be identified because the anion gap is always calculated.

Appendix 3

BRAIN DEATH

BRAIN DEATH (DEATH BY NEUROLOGIC CRITERIA)

In 1981, the Uniform Determination of Death Act (UDDA) was developed by the President's Commission for the Study of Ethical Problems in Medicine and Biomedical and Behavioral Research working in conjunction with the American Bar Association, the American Medical Association (AMA), and the National Conference of Commissioners on Uniform State Laws.

Important Milestones in the History of Defining Brain Death

- ***1968 Harvard Ad Hoc Committee***
  - *First attempt to define death by neurologic criteria*
- ***1981 Uniform Determination of Death Act***
  - *Established physiologic standards defining death as irreversible cessation of circulatory and respiratory functions (cardiopulmonary criteria) AND/OR irreversible cessation of all functions of the brain, including the brain stem (neurologic criteria)*
- ***2008 President's Council on Bioethics***
  - *Affirmed the concept of brain death*
- ***2019 American Academy of Neurology Position Statement***

Called for the uniformity of brain death determination criteria, citing variation in law and policy regarding testing procedures

The UDDA defined death as occurring in the presence of one or both of the following:

- *irreversible cessation of circulatory and respiratory functions (cardiopulmonary criteria)*
- *irreversible cessation of all brain functions, including those of the brain stem (neurologic criteria)*

The American Academy of Neurology (AAN) endorses the UDDA definition that brain death has occurred when the irreversible loss of all functions of the entire brain, including the brain stem, has occurred and has been determined by the demonstration of complete loss of consciousness (coma), brain stem reflexes, and ventilatory drive (apnea), in the absence of any reversible factors. It also recognizes that neuroendocrine function may persist in patients with irreversible injury to the brain and brain stem. This is presumed to occur because of the possible protective anatomic location of the pituitary gland and its vasculature.

At present, brain death is diagnosed clinically at the bedside when there is evidence of the complete loss of brain stem function as noted by lack of response to prescribed noxious stimuli and hypercapnia; the “apnea test.” A patient in a comatose state may exhibit some of the clinical findings of a patient that has progressed to brain death. *It is therefore imperative to rule out other causes of comatose state (toxic, metabolic, etc.) prior to concluding that brain death has occurred.*

Because there can be some ambiguity with the clinical examination, especially if there are not skilled individuals to perform the examination, as well as anatomic and physiologic limitations that prevent completion of the examination components, eg, if the patient is hemodynamically unstable to tolerate the testing or has sustained significant facial trauma, there may be a need to perform confirmatory testing. Confirmatory tests include cerebral blood flow examinations, such as four-vessel digital subtraction angiography, technetium radionuclide angiography or scintigraphy, magnetic resonance angiography, CT angiography, and transcranial Doppler studies. Ancillary testing includes EEG and evoked potentials (somatosensory, auditory, or visual). Confirmatory and ancillary testing are *performed to complement the clinical examination* and, in some jurisdictions, may eliminate the requirement for a second examiner or a second examination after a prescribed delay to reexamination.

Some limitations to confirmatory and ancillary testing include its availability at the facility, its accuracy across multiple operators and interpreters, its ability to be performed at the bedside, and whether it has any potentially deleterious adverse effects to the patient or organs (especially when considering organ donation).

Diagnosis of brain death can be further challenged by medical, cultural, and societal barriers that must be overcome before such consensus becomes possible. Barriers to the diagnosis of brain death can include the acceptance of brain death as death, religious beliefs about death, legal standards of death determination, cultural norms about death, requirements for organ donation, knowledge deficits of professionals, examination technical requirements, and availability and quality of ancillary tests.

The determination of brain death is further complicated by practice variation between hospitals and jurisdictions as well as individual physicians. In the United States, despite having accepted diagnostic criteria proposed by the AAN and allied specialty societies, it has been challenging to standardize practices of brain death determination. In other countries, practice disparities arise more because of legal, cultural, or religious differences.

Examination of the patient with concern for brain death can be challenging for many reasons. The clinical examination is the foundation of determining brain death and may be complemented by ancillary confirmatory testing as needed (**Table A3-1**). It is recommended that a protocol be developed at your facility that is supported by the guidance of the AAN, the Neurocritical Care Society (NCS), and policies set forth by your state, jurisdiction, and hospital. To facilitate training and uniformity, the NCS has developed a Brain Death Determination credentialing program which can be found at https://www.neurocriticalcare.org/education/braindeath

Brain death diagnosis by means of transcranial Doppler (TCD) ultrasound is a good example of the point-of-care ultrasound (POCUS) concept applied to critical care. It could be easily performed bedside and results are clear and reproducible. There are two options to perform the examination: spectral or "blind" devices (TCD) and transcranial coded color Doppler (TCCD), which is included in most of ultrasound machines available at the ICU.

Using both transtemporal and occipital windows, middle cerebral arteries and the basilar artery should be insonated for at least 30 seconds. If no ultrasound images are found in these windows, the proximal arteries (ipsilateral internal carotid siphon or both vertebral, respectively) are acceptable for the diagnosis of cerebral circulatory arrest. The examination must be repeated after 30 minutes.

Arterial blood pressure must be greater than 90/50 mm Hg or mean arterial pressure greater than 60 mm Hg at the beginning of the study and sustained among the different diagnostic stages.

Figure A3-1 shows a summary of cerebral circulatory arrest (CCA) patterns.

A false negative result could occur in cases of loss of tightness of the skull (large craniectomies, ventricular drainage, multiple skull fractures). In that situation, changes in intracranial pressure (ICP) or cerebral perfusion pressure (CPP) may be not so important to produce the CCA patterns. However, a large percentage of these patients evolve to CCA, so the study is not only not contraindicated, but on the contrary, its repetition over time becomes peremptory for its diagnosis.

A false positive result could occur when ancillary circulatory devices are present (aortic balloon pump, extracorporeal membrane oxygenation) in which biphasic flow may be identified in the absence of cerebral circulation.

In summary, TCD or TCCD are useful and available tools as ancillary tests for brain death diagnosis in cases in which clinical examinations are not possible or conclusive as a result of large cranial or facial destruction or depressant drugs. Physician training is simple and results are not operator-dependent.

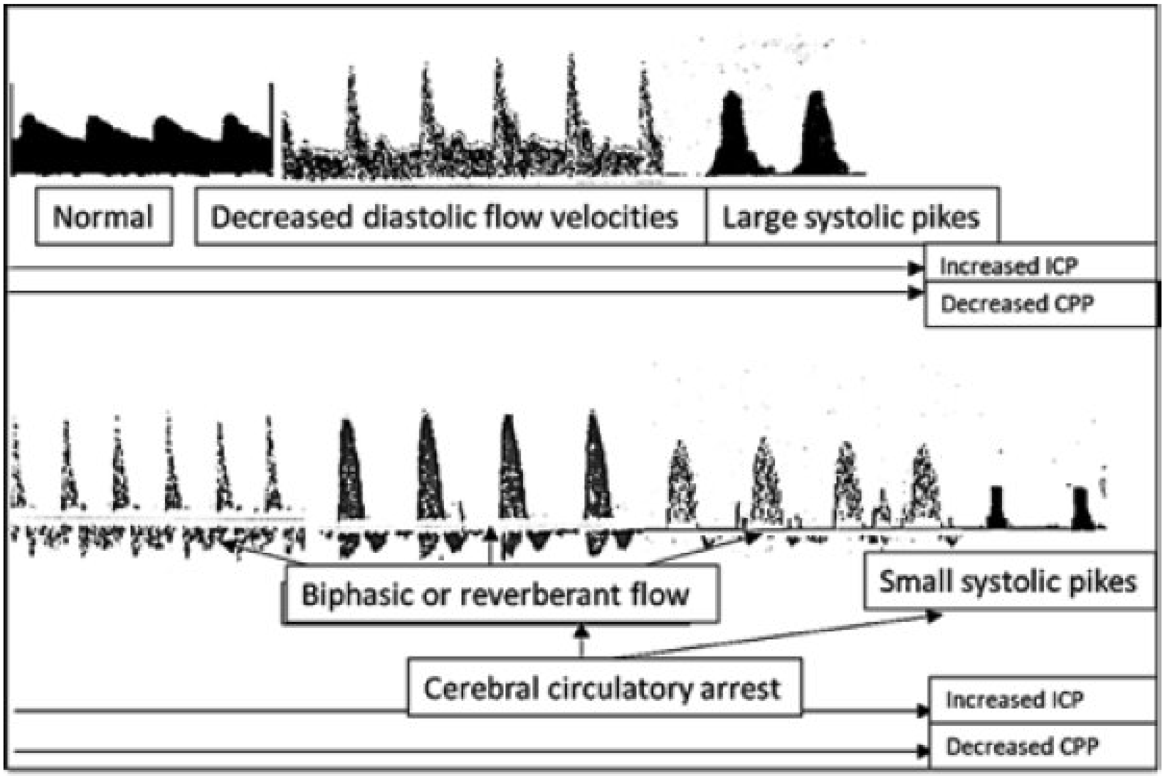
Table A3-1 Accepted Medical Standards for Brain Death

Parameter	**American Academy of Pediatrics**	**American Academy of Neurology**
Relevant age	37 weeks' gestation to 18 years of age	>18 years of age
Prerequisites	Known irreversible cause of coma	Known irreversible cause of coma
	No hypothermia or hypotension	Normal temperature or mild hypothermia; SBP > 100 mm Hg
	No metabolic disturbances	No severe electrolyte, acid-base, or endocrine disturbance
	Sedatives, analgesics, neuromuscular blockers, and anticonvulsant agents discontinued	Absence of CNS-depressant drug effect; no evidence of residual paralytics
	Defer examination for 24-48 h after acute brain injury	Wait several hours since onset of brain insult to exclude possibility of recovery
Performed by…	Attending physicians involved in care of child	Physician demonstrating competence and intimate familiarity with protocol
Cardinal findings	Coma; lack of all responsiveness; absence of eye movement or motor response to noxious stimuli	Coma; absence of motor response to noxious limb stimuli (other than spinally mediated reflexes)
	Loss of all brain stem reflexes (mid- or fully dilated pupils unresponsive to light; corneal, oculovestibular, gag, sucking, and facial movement to noxious stimuli)	Loss of all brain stem reflexes (pupillary response to light; corneal, oculoencephalic, oculovestibular, gag, cough, and facial movement to noxious stimuli)
	Apnea test (safety permitting)	Apnea test (as mandated)
	Flaccid tone and absence of movement	
Recommended confirmatory or ancillary studies	4-vessel angiography	Cerebral angiography
	Electroencephalogram	Electroencephalogram
	Radionucleotide cerebral blood flow	Cerebral scintigraphy
		Transcranial Doppler ultrasonography
Indication for confirmatory studies	If components of examination cannot be safely performed	When uncertainty exists about reliability of parts of the neurologic examination
	If apnea testing cannot be safely performed	When apnea test cannot be performed
	To reduce interexamination observation period	To shorten duration of observation period
	If uncertain neurologic examination is present	
	If uncertain medication effect is present	
	If helpful for social reasons, allowing family members to better comprehend diagnosis	
Requirement for repeat physical examinations	Two examinations by different physicians separated by observation period; apnea testing may be repeated by same physician	One neurologic examination is sufficient (some U.S. state statutes require two examinations)
Observation period between repeat examinations	24 h for term newborns (37 weeks' gestation to 30 days); 12 h for infants and children (>30 days to 18 years of age)	Not required

Abbreviations: CNS, central nervous system; SBP, systolic blood pressure

This research was originally published in JNM. Zuckier L. Radionuclide Evaluation of Brain Death in the Post-McMath Era. *J Nucl Med*. 2016;57(10):1560-1568. © SNMMI.

Figure A3-1. Brain Death Patterns


Normal
Decreased diastolic flow velocities
Large systolic pikes
Increased ICP
Decreased CPP
Biphasic or reverberant flow
Small systolic pikes
Cerebral circulatory arrest
Increased ICP
Decreased CPP

As ICP increases and CPP decreases, Doppler spectral waveforms become extinct. Complete cerebral circulatory arrest is suggested by equalization of forward and reverse flow components. Absence of flow should be considered as cerebral circulatory arrest only when the same operator had found it in a previous examination.
Reprinted from *J Neurol Sci.*, 159(2), Ducrocq X, et al., Consensus opinion on diagnosis of cerebral circulatory arrest using Doppler-sonography: Task Force Group on cerebral death of the Neurosonology Research Group of the World Federation of Neurology, 145-150, Copyright (1998), with permission from Elsevier.

Suggested Readings

1. Consensus Group on Transcranial Doppler in Diagnosis of Brain Death. Latin American consensus on the use of transcranial Doppler in the diagnosis of brain death. *Rev Bras Ter Intensiva*. 2014;26:240-252.

2. Ducrocq X, Hassler W, Moritake K, et al. Consensus opinion on diagnosis of cerebral circulatory arrest using Doppler-sonography: Task Force Group on cerebral death of the Neurosonology Research Group of the World Federation of Neurology. *J Neurol Sci*. 1998;59:145-150.

3. Milliken A and Uveges M. CE: Brain Death: History, Updates, and Implications for Nurses. *Am J Nurs*. 2020;120(3):32-38.

4. Russell JA, Epstein LG, Greer DM, Kirschen M, Rubin MA, Lewis A. Brain death, the determination of brain death, and member guidance for brain death accommodation requests: AAN position statement. *Neurology*. 2019 January 2.

5. Schiff ND, Fins JJ. Brain death and disorders of consciousness. *Curr Biol*. 2016:26(13):R572-R576.

6. Shemie SD, Hornby L, Baker A, et al. The International Guidelines for Determination of Death phase 1 participants, in collaboration with the World Health Organization. International guideline development for the determination of death. *Intensive Care Med*. 2014;40:788-797.

7. Wahlster S, Wijdicks EFM, Patel PV, et al. Brain death declaration: practices and perceptions worldwide. *Neurology*. 2015;84:1870-1879.

8. Zuckier LS. Radionuclide Evaluation of Brain Death in the Post-McMath Era. *J Nucl Med*. 2016;57(10):1560-1568.

Appendix 4

ORGAN DONATION

Organ donation is a process consisting of giving an organ or a part of an organ to be transplanted into another person. Over the past 10 years, transplant surgery has advanced in the organ recovery and preservation process in the hopes of meeting the increasing community need for organ transplantation. Transplant surgery has evolved to meet the public needs for function and quality of life with the expansion of organ donation to include tissue graft transplantation, such as extremity and face, as well as infertility with uterine transplant. Organ donation can occur with a deceased donor or a living donor.

I. HISTORY

The first successful human organ transplant occurred in 1954. In 1968, the Uniform Anatomical Gift Act (UAGA) provided the legal foundation upon which human organs and tissues could be donated for transplantation. Since 1972, all states in the United States and the District of Columbia have adopted this Act, or amended forms of this Act. Worldwide over 100,000 transplants occur yearly. In the United States, almost 40,000 transplants were coordinated in 2019. Unfortunately, the waiting list for men, women, and children for organ transplantation still is in excess of 100,000 in the United States with more being added to the list daily. On average, only 3 in 1000 deaths allow for organ donation.

The dead-donor rule was developed by Robertson in 1999 to refer to a norm that organ donation policies have implicitly held since the beginning of multiorgan procurement in the late 1960s. Although it is not a law, the rule established the relationship between the two most relevant laws governing organ donation from deceased donors: The Uniform Anatomical Gift Act and state homicide law. The key point is that organ donation must not kill the donor; the person must first be declared dead. It applies only to organ donation from deceased donors.

As organ transplantation evolved, the regulation and oversight of the process evolved as well. In 1984, The National Organ Transplant Act (NOTA) called for the creation of an Organ Procurement and Transplantation Network (OPTN). The OPTN is overseen by the Health Resources & Service Administration (HRSA), an agency of the U.S. Department of Health and Human Services (HHS). The United Network for Organ Sharing (UNOS), an independent nonprofit company incorporated in 1984, is charged with operationalizing the goals of the OPTN. Examples of critical requirements the OPTN must support include the establishment and maintenance of an organ transplant waitlist, the process and procedures to match organ donors to recipients, securing an allocation process that is equitable, ethical, and medically sound in manner, the ability to collect and process data into meaningful information to improve the transplant process, the presence of a 24-hour availability, and the establishment of a forum for public comment on policy and process. The United States is divided into different regions to facilitate transplantation. These regions help determine how the 200+ transplant hospitals, 50+ organ procurement organizations, and 150+ histocompatibility laboratories interact with one another.

A. Organ Procurement Organization (OPO)

An organization designated by the Centers for Medicare and Medicaid Services (CMS) is responsible for the procurement of organs for transplantation and the promotion of organ donation. OPOs and their transplant coordinators (TCs) serve as the vital link between the donor and recipient and are responsible for the identification of donors and the retrieval, preservation, and transportation of organs for transplantation.

There are several similar organizations around the world, but the one that has had more impact in organ donation is the Spanish National Transplant Organization (ONT). Since its creation in 1989, the so-called “Spanish model" allowed the increase from 14 donors per million population to 48 in 2018, making Spain the world leader in organ donation. This model has been recreated in Latin-America and Europe with different rates of success. The model is based on "transplant coordinators" who are physicians and/or nurses from intensive care units that take care of the complete organ donation process, from donor identification and management to the family interview.

In the United States, the administration of organ allocation and geographic representation requires the territorial division into 11 different regions. Members of each region share policy structure and are linked primarily to the other members of the region. Historically, when an organ is available, the priority is given to the members of the region. As transplant surgery evolves, so has the process for organ allocation. In March 2021, OPTN launched a new policy for kidney and pancreas to increase equity in transplant access nationwide. This new policy consists of replacing distribution based on donation service area and OPTN region with a more consistent measure of distance between the donor hospital and the transplant hospital. For more information regarding these regions and about the OPTN, you can visit https://optn.transplant.hrsa.gov.

II. DONOR CLASSIFICATION

A. Donationafter Declaration of Brain Death (Controlled)

The recovery of organs or tissue after irreversible damage of cerebral and brain stem function; characterized by absence of electrical activity in the brain, blood flow to the brain, and brain function as determined by clinical assessment of responses. A brain-dead person is dead, although his or her cardiopulmonary functioning may be artificially maintained for some time.

Ongoing communication by the healthcare team with the family is encouraged when a patient is expected to progress to brain death. Prior to pronouncement of brain death, the regional OPO should be contacted by the healthcare team for patient evaluation for possible organ donation. Once the pronouncement of brain death is made, further conversations with the family must occur to discuss the pronouncement and perhaps explain what brain death means. Family is informed of the brain death declaration prior to the discussion of organ donation. The TC of the OPO is introduced to the family and then communicates with the family about the opportunity for organ donation and obtains consent. The donor patient must be supported until the recovery process occurs in the operating room after coordination with family and recovery surgeons.

B. Donation After Circulatory Death (DCD)

Recovery of organs and or tissues from a donor whose heart has irreversible cessation of circulatory and respiratory function, previously referred to as donation after cardiac death, non-heart-beating or asystolic donation. This process can be controlled or uncontrolled depending on the organ donor's clinical status.

Controlled

Potential donors are limited to patients who have died, whose death is imminent, or whose medical treatment no longer offers a medical benefit to the patient as determined by the patient, the patient's authorized surrogate, or the patient's advanced directive in constitution with the healthcare team. Prior to the OPO initiating discussion regarding potential DCD organ donation, the OPO must confirm the decision to withdraw life-sustaining medical interventions. Prior to withdrawal of life-sustaining measures, the healthcare team and OPO coordinate donation discussion with the patient's family or legally appointed representative.

Once organ donation consent has been obtained by the TC, a time is coordinated with the family and recovery surgeons for the patient to be separated from all life-supporting interventions and comfort care is initiated. This usually occurs in the operating room but may occur in the ICU and the family may or may not chose to be at the patient bedside. The patient is pronounced dead by circulatory/cardiac death. Pronouncement of death is made by the donor hospital healthcare team member who is authorized to declare death and must not be part of the organ recovery team. This must occur within 60 to 90 minutes of separation of life support for the donation to proceed. If transition to comfort measures occurs in the ICU, the patient is transported to the operating room; if comfort care is initiated in the OR, the family is escorted out of the OR. A period of 2 to 10 minutes of asystole (pulselessness, apnea, unresponsiveness) is observed prior to organ recovery in the operating room. Up to 10% of potential donors maintain cardiac activity for more than 90 minutes after discontinuation of life support. These individuals are not candidates for organ donation and will receive ongoing end-of-life care.

Uncontrolled

Rapid organ recovery donation after circulatory death (uncontrolled DCD) involves recovery of organs following death from an unexpected circulatory arrest and can be an out-of-hospital, refractory cardiac arrest or an unexpected cardiac arrest in hospital. Optimally an OPO TC will be present or available during the arrest event; if a representative is not present, the OPO should be contacted by healthcare staff not participating in the resuscitation. After resuscitation attempts are judged futile by the healthcare team, the OPO assesses the patient as eligible to proceed with rapid organ recovery. The family/legal representative must have made the decision to withdraw life support and stop resuscitative efforts prior to the discussion of donation. Resuscitation is continued as the TC has a conversation with family regarding possible donation. If consent is obtained and the plan is to move forward with rapid organ recovery, all interventions are terminated and the patient is pronounced dead. The diagnosis of death may occur after resuscitation is terminated on scene or after arrival to the hospital. There is a "no touch" period after which death is determined, usually 2 to 5 minutes. After this time, organ preservation may be restarted with cardiac compressions and mechanical ventilation initiated to preserve the organs for donation only. Compressions are maintained by healthcare staff or using a compression/CPR device until a recovery surgeon and OR are available.

C. Living Donation

A living individual from whom at least one organ is recovered for use in a transplant. A kidney, or a portion of a liver, lung, pancreas, or intestine are examples.

III. DONATION PROCESS

A. Potential Organ Donor Recognition

Consider patient as a potential organ donor and communicate with OPO:

- At the first indication the patient has sustained a non-survivable neurologic or anoxic injury/illness
- Prior to the first formal brain death examination
- Prior to family discussion of do-not-resuscitate (DNR) or withdrawal of support
- Patient has sustained: anoxia, cerebrovascular accident, head trauma

B. Communication

Consider phases of communication with the family: Provide up-to-date information in small amounts. Set aside time to answer questions. Use visual aids to describe the brain injury. When possible, bring the family to the bedside to observe clinical tests. Choose words carefully when discussing the patient's condition. Do not mention donation until a systematic, timed, collaborative approach can be orchestrated with the OPO transplant coordinator and a member of the care team.

- **Phase 1** (Serious Injury) YOUR RELATIVE has sustained severe damage to his/her brain. We are doing everything we can but he/she may not recover.

  – Critical care team continues to support the potential organ donor patient through all phases.

- **Phase II** (Grave Prognosis) Despite everything we have done, things are getting worse. There is nothing more we can do to save your loved one's life. Ensure that OPO has been notified.
- **Phase III** (First Examination for brain death) YOUR LOVED ONE appears to be dead because there is no brain function. We have begun a series of tests to confirm this. We want to be extremely thorough and careful to ensure that we are absolutely correct. (Provide the family with information about additional testing and timeframes.)
- **Phase IV** (Pronouncement) We have finished the testing and found that YOUR RELATIVE______ has died @ (INFORM family of the time of death). (Where appropriate, repeat clinical examination with the family present.)
- **Phase V** (Team Huddle and Care Team Introduces the OPO TC) This is ______, a member of our team and a specialist who works with families such as yours.

The communication process for controlled and uncontrolled DCD would not include a brain death examination or pronouncement prior to discussion of donation with the family. For the DCD communication process, a family discussion with the appropriate hospital recommended support staff present (palliative care, Chaplain service, case management) should be conducted to discuss goals of care. The OPO TC should be available and present in the hospital at the time of the meeting. If the family wishes to transition to comfort measures/withdraw/hospice, this would be the time to introduce the OPO TC to discuss DCD organ donation.

C. Management Goals for Potential Organ Donors

In 2015, the Society of Critical Care Medicine, the American College of Physicians, and the Organ Procurement Organization Donor Management Task Force published a Consensus Statement in organ donation. More recently (2020), the Spanish Society of Intensive Care Medicine (SEMICYUC) updated their guidelines on regards to the goals for the management of potential organ donors.

Some of the points highlighted in those position papers are summarized below.

Fluid Management Recommendations

- Crystalloids (isotonic saline) is the preferred fluid therapy
- Colloid infusions can be used as a bolus to treat hypotension
- Hypotonic saline can be used to treat hypernatremia
- Bicarbonate might be needed to treat metabolic acidosis
- Replacement of fluids should be directed by hemodynamic monitoring

Monitoring Goals and Recommendations

- Continuous cardiac monitoring and SpO_2
- Hourly vital signs and Input/Output documentation
- Left ventricular ejection fraction > 45%
- Maintain urine output > 1mL/kg/h and < 4mL/kg/h
- Goal temperature 36-38°C (96.8-100.4°F) (warming/cooling blanket, as needed)

Donor management focuses on improving and maintaining appropriate organ perfusion. Critical care management is still required during this phase of care. Interventions, such as mechanical ventilation, renal replacement therapy, and titration of vasopressors, are necessary to achieve the goal of organ transplantation. OPOs work in coordination with hospitals and healthcare providers on management recommendations and goals. Institution and OPO collaborative projects, such as the creation of donor management order sets and protocols, have improved donor management and successful organ recovery for transplantation.

IV. ORGAN PLACEMENT PROCESS

When organs are donated, the regional OPO accesses the national transplant computer system. Information about the donor is entered into the system and a donor/recipient match is run for each donated organ. The resulting match list of potential recipients is ranked according to criteria defined in that organ's allocation policy. Each organ has its own specific criteria.

Using the match list of potential recipients, the regional OPO's TC contacts the transplant center of the highest ranked patient. If the organ is not accepted, the next potential recipient's transplant center on the match list is contacted until the organ is placed. Once the organ is accepted for a patient, transportation arrangements are made and transplant surgery is scheduled.

This narrative is a summary of organ donation. It does not encompass all involved with the process. The intention of this section is to introduce organ donation and provide an overview of the history, the types of organ donation, and to state the importance of ongoing critical care management of the donor patient. For more information on the process, please refer to the suggested readings and consider contacting your regional OPO.

Suggested Readings

1. Chamorro-Jambrina C, Munoz-Ramırez MR, Martınez-Melgar JL, Perez-Cornejo MS. Organ donor management: Eight common recommendations and actions that deserve reflection. *Med Intensiva*. 2017;41(9):559-568.
2. Institute of Medicine, Committee on Non-Heart- Beating Transplantation II, "Non-Heart-Beating Organ Transplantation-Practice and Protocols", report from conference convened on May 24, 25, 1999. https://pubmed.ncbi.nlm.nih.gov/25077239/
3. Korte C, Garber JL, Descourouez JL, Richards KR, Hardinger K. Pharmacists' guide to the management of organ donors after brain

death. *Am J Health Syst Pharm*. 2016;73(22):1829-1839.

4. Kotloff RM, Blosser S, Fulda GJ, et al. Management of the Potential Organ Donor in the ICU. *Crit Care Med*. 2015;43(6):1291-1325.
5. Organ Procurement and Transplant Network. US Department of Health and Human Services website. https://optn.transplant.hrsa.gov. Accessed May 2, 2020
6. Organ Transplant Data. US Department of Health and Human Services website. https://data.hrsa.gov/topics/health-systems/organ-donation. Updated February 21, 2019. Accessed May 2, 2020.
7. Ortega-Deballon I, Hornby L, Shemie SD. Protocols for uncontrolled donation after circulatory death: a systematic review of international guidelines, practices and transplant outcomes. *Crit Care*. 2015;19(1):268.
8. “Report of a National Conference on Donation after Cardiac Death”, conference held April 7,8, 2005, Philadelphia. https://www.onelegacy.org/docs/NationalConferenceOnDCD_2006.pdf
9. Thoracic and Critical Care Community. American Society of Transplantation. https://www.myast.org/about-ast/about-ast. Accessed May 2, 2020.
10. United Network for Organ Sharing. https://unos.org/about/history-of-unos/ Accessed May 2, 2020.
11. US Department of Health and Human Services Advisory Committee on Organ Transplantation Recommendations, November 6,7, 2003. https://www.organdonor.gov/about-dot/acot/acotrecs2935.html

Suggested Websites

1. Protocolo Nacional de Mantenimiento del Potencial Donante de Organos (SEMICYUC-ONT) https://semicyuc.org/2020/05/protocolo-nacional-demantenimiento-del-potencial-donante-de-organos-semicyuc-ont/
2. United Network for Organ Sharing (UNOS). https://unos.org/
3. OPTN: Organ Procurement and Transplantation. https://optn.transplant.hrsa.gov/